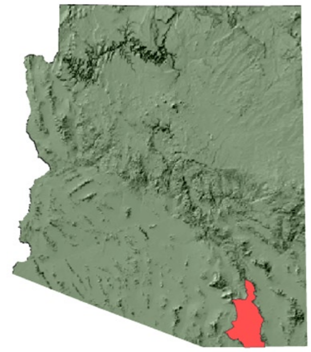
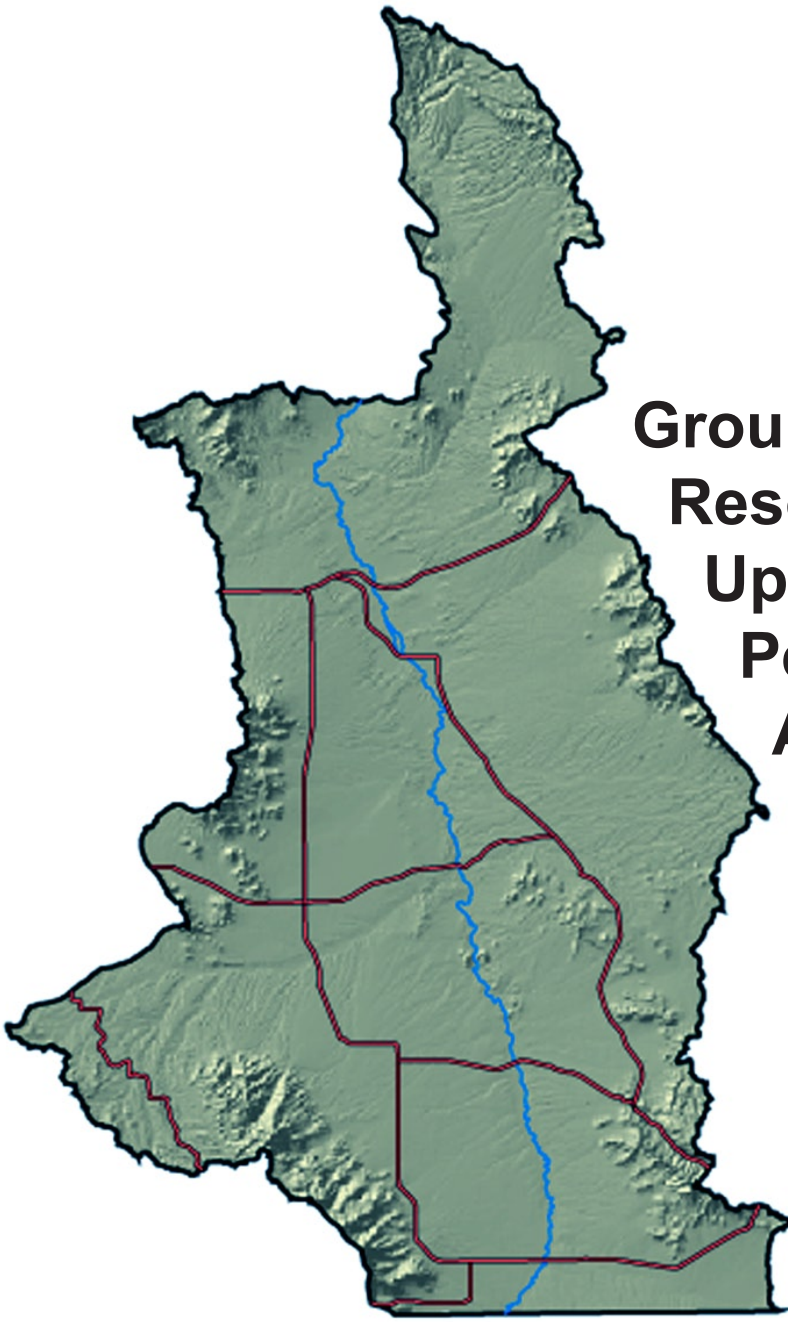
ARIZONA DEPARTMENT OF WATER RESOURCES
SECURING ARIZONA'S WATER FUTURE





Groundwater Resources of the Upper San Pedro Basin, Arizona

Technical Report to the Upper San Pedro Basin AMA Review Report

February 2005

Arizona Department of Water Resources
500 North Third Street
Phoenix, AZ 85004

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CHAPTER 1 - Introduction

Purpose and Scope

This report describes the hydrology and water uses within the Upper San Pedro (USP) basin. It is intended to provide a scientific background for evaluation of the USP basin to assist in the determination of whether designation of the USP basin as an Active Management Area (AMA) is merited under the Arizona Groundwater Code of 1980.

As provided by A.R.S. § 45-412 of the Arizona Groundwater Code, the Director of the Department of Water Resources (Department) reviews areas within Arizona, which are not already included within an AMA, to determine whether such areas should be designated as an AMA. The Director may designate an AMA if the Director determines that any one of three statutory criteria exists. These statutory criteria relate to groundwater supplies, land subsidence and water quality in the area under consideration for designation. Any newly designated area may include more than one groundwater basin, but may not be smaller than one groundwater basin or include only a portion of a groundwater basin (with the exception of the regional aquifer systems of northern Arizona). A.R.S. § 45-412 states:

A. *The director may designate an area which is not included within an initial active management area, pursuant to § 45-411, as a subsequent active management area if the director determines that any of the following exists:*

   1. *Active management practices are necessary to preserve the existing supply of groundwater for future needs.*

   2. *Land subsidence or fissuring is endangering property or potential groundwater storage capacity.*

   3. *Use of groundwater is resulting in actual or threatened water quality degradation.*

B. *An active management area designated pursuant to this section may include more than one groundwater basin but shall not be smaller than a groundwater basin or include only a portion of a groundwater basin, except for the regional aquifer systems of northern Arizona.*

C. *The director shall periodically review all areas, which are not included within an active management area to determine whether such areas meet any of the criteria for active management areas as prescribed in this section.*

In 1988, the Department examined the water resources of the USP basin and evaluated the need to create an AMA (Putman and others, 1988). At that time, the Director determined that the statutory criteria for designating an AMA had not been satisfied. In this report, the Department examines historic and current information concerning the geology, groundwater hydrology, and water uses in the USP basin in the context of the three statutory criteria of A.R.S. § 45-412. For purposes of this report, water in an aquifer or pumped from a well is referred to as groundwater. This report will be incorporated into the USP Basin AMA Review Report (AMA Review Report), which evaluates the need for an AMA in the USP basin (Arizona Department of Water Resources, 2005, in preparation).

Location, Topography, and Climate

(Adapted from Putman, Mitchell and Bushner, 1988)

The USP basin is located in southeastern Arizona about 50 miles southeast of Tucson (Figure 1). The basin boundaries were designated by the Department on July 20, 1982 pursuant to A.R.S. §45-403 and §45-404. The basin boundaries are defined by ADWR as "the surface watershed of the San Pedro River from the Republic of Mexico downstream to the area referred to as "The Narrows" north of Benson, and in addition, the upper drainage areas of Hot Springs and Kelsey Canyons which enter the San Pedro River north of "The Narrows." The USP basin is divided into two sub-basins: the Allen Flat sub-basin, which is the upper watersheds of Tres Alamos Wash, Hot Springs and Kelsey Canyons; and the Sierra Vista sub-basin, which is the watershed of the San Pedro River upstream from "The Narrows," exclusive of Upper Tres Alamos Wash (Arizona Department of Water Resources, 1982). See Figure 2 for an overview of the USP basin.

The Allen Flat sub-basin comprises about 10% of the area of the entire USP basin. The northern half of Allen Flat is tributary to the Lower San Pedro (LSP) basin. There are three surface water tributaries that drain the northern half of the Allen Flat sub-basin: Hot Springs Canyon, Bass Canyon and Kelsey Canyon. Tres Alamos Wash drains the southern half of the Allen Flat sub-basin, which is tributary to the USP basin. Water use in the Allen Flat sub-basin is mostly for stock purposes.

The USP basin is drained by the San Pedro River. The San Pedro River drains about 2500 square miles at the U.S. Geological Survey (USGS) streamgage near Benson at a location known as "The Narrows" and has a total length of about 90 river miles at that point. About 696 square miles of this drainage area are in Mexico. A few tributaries to the river begin on the southwest slopes of the Huachuca Mountains, in the San Rafael Valley. These tributaries drain about 54 square miles of the United States before entering Mexico in T24S, R19E.

The San Pedro River enters the United States from Mexico, near Palominas, Arizona, in Section 18, T24S, R22E. The river flows northward for about 62 river miles before leaving the USP basin at "The Narrows." The river is perennial in several places and is intermittent in other reaches, flowing seasonally in response to climatic and water use variables. The Babocomari River, its major tributary, is also perennial in places, although not at its confluence with the San Pedro River. All other drainages are tributary to the river and, with the exception of a few small streams in the mountains surrounding the basin, are ephemeral, flowing briefly after significant rainfall events.

Four stream gaging stations have existed at one time or another on the San Pedro River within the USP basin (Figure 2). At the present time, the USGS maintains three stations at Palominas, Charleston, and Tombstone; the gaging station at "The Narrows" has been discontinued. USGS gaging records also exist for seven smaller drainages in the basin, but for shorter periods of time (Evans, 2001). Appendix A lists the period of record for the 11 stream discharge monitoring sites shown on Figure 2.

Several springs are found in consolidated rocks and basin-fill deposits throughout the watershed. In the mountains, springs are recharged from runoff resulting from precipitation and snowmelt. The runoff is intercepted by fractures in the rock where it is transmitted to springs. Springs also occur in areas near the San Pedro River where low-conductivity deposits intersect the land surface. Most springs yield several gallons per minute with a few large springs producing up to several hundred gallons per minute.

The mountains that border the basin range in height from 5,000 to nearly 10,000 feet. These mountains are the Huachuca, Mustang, Whetstone, and Rincon Mountains on the west and the Mule, Dragoon, Little Dragoon, and Winchester Mountains on the east. Much of the valley floor of the basin is grassland. Elevations along the river range from about 4,200 feet above mean sea level at the International Border to about 3300 feet above mean sea level at "The Narrows" north of Benson. Biotic communities of the USP basin vary widely with sub-alpine and montane forests in the higher elevations, evergreen woodlands at lower elevations in the mountains, and zoning to chaparral at lower elevations (Brown, 1982). Desert grasslands and scrub/desertscrub cover a large portion of the valley floor and riparian vegetation exists along much of the San Pedro River and segments of the Babocomari River.

Because of its higher elevation, the USP basin does not experience the extreme desert heat as does much of the rest of the southern part of the state. Summers are moderately warm, with afternoon maximum temperatures normally ranging from the middle 80's to 90°F.

Readings above 100°F rarely occur in the higher elevations but are quite frequent in the lower elevations of the USP basin in July and August. In winter, warm days and cool nights characterize the climate of the USP basin.

The average annual precipitation ranges from about 11 inches at Benson to 19 inches at Bisbee. The mountains surrounding the basin receive greater amounts (Sellers and Hill, 1974). Total annual precipitation can vary considerably from year to year. Precipitation in the USP basin generally occurs during two periods in the year. Precipitation during the summer season of June through October is typically several inches greater than the winter season of November through February (Pool and Coes, 1999). The wet summer season occurs when moist tropical unstable air from the Gulf of Mexico moves northwest into Arizona (Sellers and Hill, 1974; Hereford, 1993). Afternoon and evening showers and thundershowers develop as the warm, moist air is forced up the southern slopes of mountains and is sufficiently cooled. Although these storms are usually of short duration, they are intense enough to occasionally create localized flash flooding. During this "monsoon" season, precipitation is at its maximum on the windward or southeastern side of the mountains. Locations near major mountain ranges are more likely to receive greater amounts of precipitation during these months (Sellers and Hill, 1974). Table 1 summarizes temperature and precipitation data for locations in the USP basin using data from the Western Regional Climate Center (Western Regional Climate Center, 2003).

The winter rainy season in the USP basin occurs when middle latitude cyclonic storms intensify off the California coast and move east and southward across the western United States. When these frontal systems move far enough south to affect southern Arizona, they may produce several days of gentle rains and moderate winds, and snow on occasions. The snow fraction usually is a relatively insignificant contribution to total annual precipitation in the USP basin although it may remain visible on the higher mountains for a few days to several weeks (Sellers and Hill, 1974).

Pool and Coes (1999) analyzed precipitation record from four stations in the basin. Annual precipitation data at Tombstone reflected a decreasing trend of about 1 inch during the period of record, 1897-1997 (Pool and Coes, 1999). Pool and Coes (1999) noted that long-term winter precipitation amounts showed no decline; summer precipitation showed a decrease of about 1 inch over the period of record, similar to the annual data.

Figure 1. Statewide Location Map.

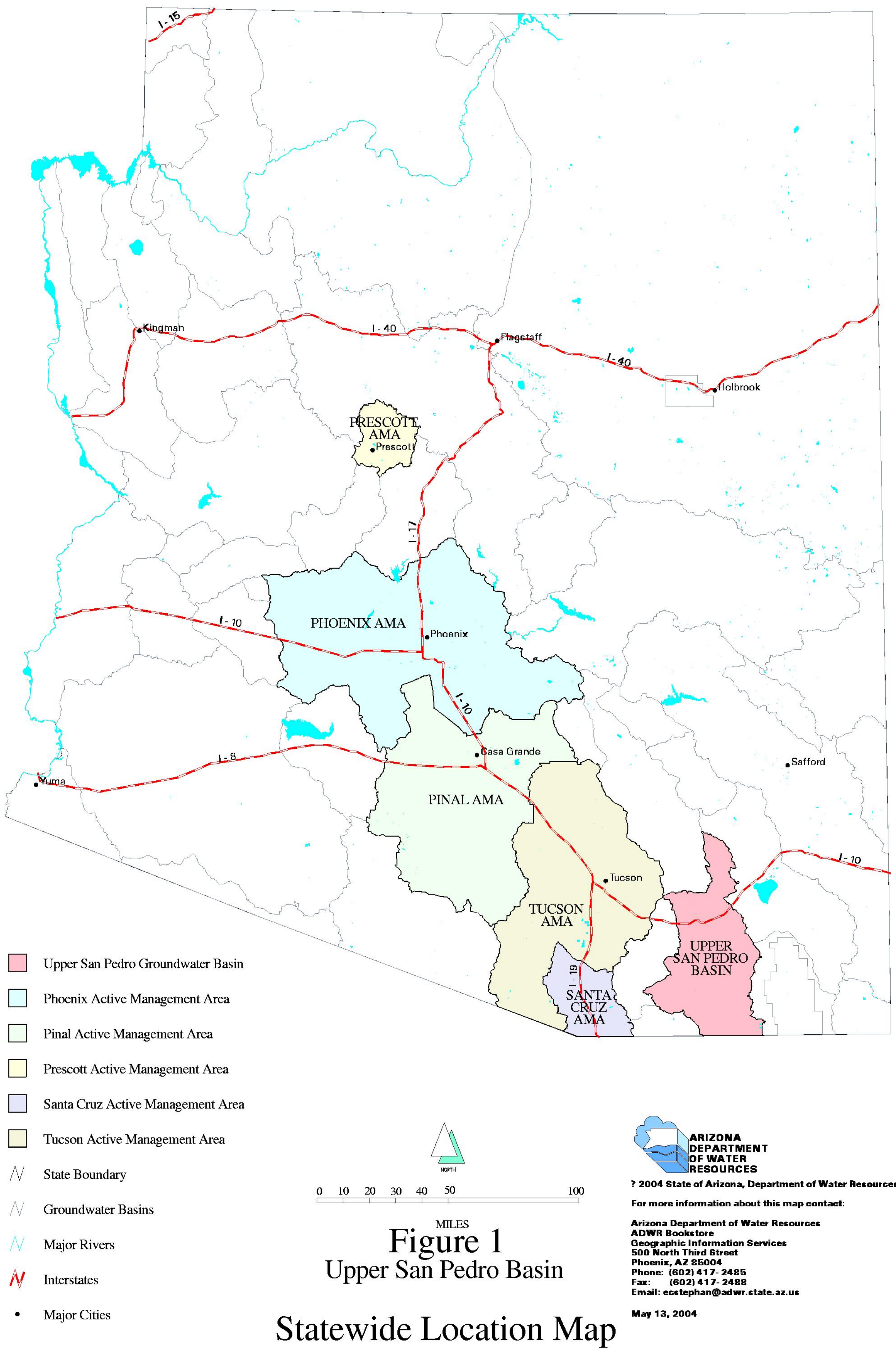
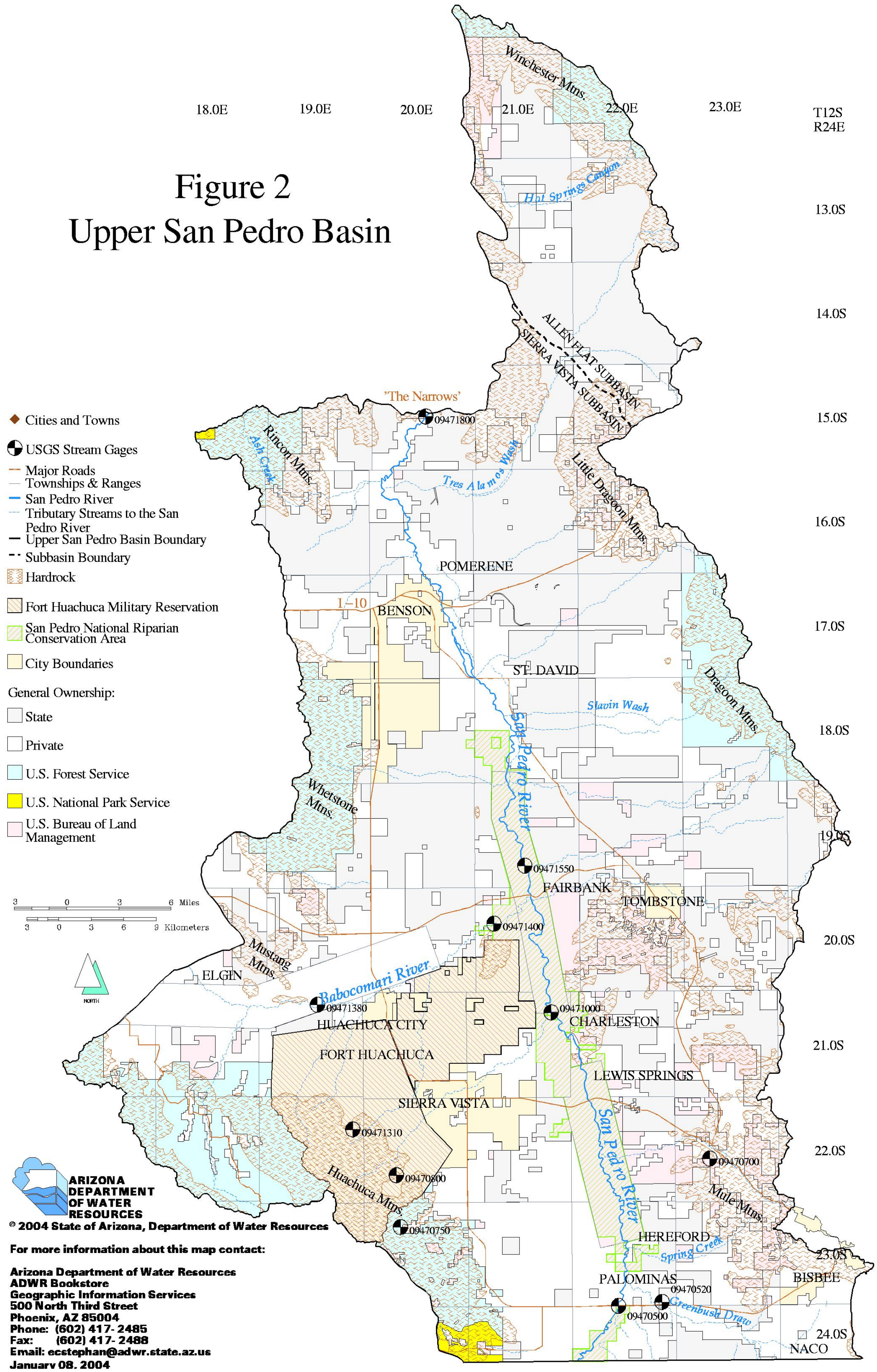


Figure 2. Upper San Pedro Basin.



High temperatures and low humidity result in high evaporation rates in the basin. Estimated lake evaporation rates in the USP basin are about 60-65 inches per year (Arizona State University, 1975).

Table 1. Summary of Annual Precipitation and Temperature Data at Weather Observation Stations in the Upper San Pedro Basin.

Station	Period of Record	Elevation (ft. abv. mean sea level)	Avg. Annual Temp. Min	Avg. Annual Temp. Max. (°F)	Avg. Annual Precipitation (in.)
Benson	1894-1975	3,590	45	80	11.3
Bisbee	1892-1985	5,300	49	74	18.6
Fort Huachuca	1900-1981	4,664	49	75	15.6
Sierra Vista	1982-2002	4,623	49	77	14.7
Tombstone	1893-2002	4,610	49	77	13.9

(Data from Western Regional Climate Center, 2003; www.wrcc.dri.edu)

Brief History of Water and Land Use

Water is used in the USP basin for a variety of purposes, including municipal, industrial, military and domestic uses, agricultural and stock use, and by wildlife and riparian systems primarily associated with the San Pedro and Babocomari Rivers. Discussed below is historical information concerning water and land use in the USP basin. This information is presented for background purposes.

The earliest records of uses of water were made by the Spanish exploratory expeditions of the 1600 and 1700s. The Spanish noted a number of Sobaipuri villages associated with farming and also noted a river with a somewhat different character than found today. Villages at Quiburi, downstream of the mouth of the Babocomari River, and a number of other places were noted and native population was estimated at about 2,000 inhabitants in the area now known as the USP basin. In addition, the Spanish noted extensive grasslands and a river of cienegas, generally broad and un-incised banks, few trees, and many beaver and fish. Direct diversion of water from the river into canals for irrigation was common (Officer, 1987; Arizona State Land Department, 1997).

As the Spanish began to expand their influence into the basin, so did the Apache Indians (Officer, 1987). Skirmishes between the Sobaipuri, Apache, and Spanish kept the basin on the Spanish frontier. The Spanish presidio at Terranate near the site of Fairbank represented one attempt to protect settlers and the Sobaipuri Indians during the mid-1770s. Its commander abandoned this outpost in 1779, citing pressure by the Apaches as the reason for abandonment (Officer, 1987). In 1821, Mexico won its independence from Spain and settlement attempts continued, as did documentation of conditions in the basin. Mexican land grants were made in 1827, 1828, and 1832 to Mexican settlers in the basin (Officer, 1987).

American mountain men were the first to document the conditions in the basin in English, and noted many wild cattle in the basin and many beaver as well. James Ohio Pattie referred to the San Pedro River as the "Beaver River" and trapped along its length in 1824-25 and 1827-28 (Pattie, 1834, in Officer, 1987). Pattie noted the absence of large trees along the banks of the river and its generally un-incised nature, although several later travelers noted areas where the riverbanks were high enough and steep enough to prevent wagons from crossing (Arizona State Land Department, 1997). Abundant "trout" were often noted. These are thought to be Colorado squawfish, now absent from the river system (Arizona State Land Department, 1997). Settlers from Tucson, escorted by Mexican soldiers for protection from the Apaches, diverted water from the San Pedro to farm land near the confluence of Tres Alamos Wash and the River (Arizona State Land Department, 1997).

The Mexican-American War of 1843-46 brought additional documentation by military parties passing through the basin. In 1854 the Gadsden Purchase made the USP basin part of the United States. The basin was transited by surveyors for roads and rail lines in the 1850's and 1860s, and Benson was established as a railroad town in 1857 (Arizona State Land Department, 1997). Discovery of lead, copper, and silver at Bisbee and Tombstone brought additional settlement and the towns of Charleston and Fairbank were founded as mill towns in the early 1880s. Railroads were built to support the mines. Extensive woodcutting for timbers for mine shafts, railroad ties, housing, and cooking caused a great change in the vegetation of the basin about this time (Arizona State Land Department, 1997).

Farming and ranching was again established in the 1860's through the 1880's, and the first use of artesian wells in Arizona occurred in the St. David area in 1887 (Bryan and others, 1934). In 1881, a post office was established at St. David.

The latest stream entrenchment episode of the San Pedro River began in 1883 near Charleston. By the early 1890s entrenchment had spread along the length of the river (Arizona State Land Department, 1997). Waters and Haynes (2001) noted that entrenchment and depositional episodes were common over the last 10,000 years. During the 1950's, the San Pedro River channel began to stabilize and deposition of sediment was relatively equal to erosion of sediments (Hereford, 1993).

By 1899, about 3,500 acres of land were estimated to be under cultivation in the Upper and Lower San Pedro basins (Arizona Department of Water Resources, 1991). Benson and Bisbee were the population centers of the basin (although part of Bisbee lies just outside the basin boundary, its supply wells are within the basin). Bryan and others (1934) list more than 4,200 acres under cultivation in the upper basin in that year. Of that, about 3,300 acres were listed as being irrigated by diversions of the St. David Ditch and the Benson Ditch. About 650 acres of alfalfa were irrigated on the Warren Ranch near Bisbee using groundwater pumped from the mines. Bryan and others listed small acreages in various parts of the USP basin that were irrigated using pumped wells. They also discussed the irrigation of more substantial plots of land near Palominas and Hereford using canal diversions and flowing wells, but did not quantify the land under cultivation. They also noted that there was no use of pumped wells for irrigation in the St. David-Pomerene area, but that flowing wells supplied supplemental irrigation water. Pumped wells were used mostly as a supply for households and gardens (Bryan and others, 1934).

Heindl (1952) listed 5,600 acres under cultivation in that year. About 4,000 acres were in the northern part of the USP basin, and 1,600 acres in the southern portion. He estimated agricultural demand at 17,000 acre-feet per year, using a demand rate of 3 acre-feet per acre of cropland. He also estimated that 15% of the water applied to the land returned to the aquifer as recharge, reducing agricultural use to 14,500 acre-feet per year. Domestic and stock use was estimated at 1,500 acre-feet per year, and military and municipal demand at 2,250 acre-feet per year. Bisbee was not included in his demand figures.

Systematic data collection on water use began in 1966 by the USGS. Prior to this time, data on water use were not collected in a regular or comprehensive manner. Roeske and Werrell (1973) estimated a total basin water use of about 35, 400 acre-feet in 1968. They estimated that 22,100 acre-feet were used for agriculture, 6,600 acre-feet for mining and industrial purposes, and 6,600 acre-feet for municipal and other purposes. Their estimate did not include riparian uses.

The quality and quantity of data on estimated water use increases after 1966. Important sources of data are the Arizona Corporation Commission, the USGS, records volunteered by water companies in the basin, and the Department's Hydrologic Survey Report for the San Pedro basin (Arizona Department of Water Resources, 1991).

The USGS estimated that about 31,000 acre-feet of water were pumped in the USP basin in 1985 (U.S. Geological Survey, 1986). About 20,500 acre-feet were used for agricultural purposes, primarily in the northern part of the USP basin. About 10,200 acre-feet were used for municipal, industrial, military, and domestic purposes, primarily in the southern part of the USP basin.

Based on aerial photos, Putman and others (1988) estimated that about 7,150 acres were farmed in 1977, and about 9,800 acres in the 1983-85 time period in the Sierra Vista sub-basin. Use of both surface water and groundwater by riparian plants and riverine evaporation was estimated to be about 31,000 acre-feet per year for the USP basin (Putman and others, 1988). Groundwater modeling efforts and other recent studies indicate that about half of the riparian use is supplied by groundwater and the other half by surface flows of the Babocomari and San Pedro Rivers (Corell and others, 1996; Scott and others, 1996; Chehbouni and others, 2000). This is further discussed in the section on groundwater budget outflows.

In the Sierra Vista sub-basin, non-agricultural groundwater use was estimated to be about 11,000 acre-feet in the Sierra Vista sub-basin (Putman and others, 1988). The Department used an estimate of 11,000 acre-feet of groundwater pumpage for 1991 in a later report on the southern half of the Sierra Vista sub-basin (Corell and others, 1996). The 1996 report documented development of a groundwater model used to evaluate the impacts of groundwater withdrawals on the groundwater system. The model study area did not include Benson or Tombstone, nor the area along the upper Babocomari River west of Fort Huachuca, nor the St. David and Pomerene farming areas, nor did it include the Allen Flat sub-basin.

Groundwater use in the basin has decreased substantially since the mid-1980's, due to extensive conservation efforts and the operation of recharge projects by Fort Huachuca and the City of Sierra Vista, and because of the retirement of farmlands in the southern and central parts of the basin by the U.S. Bureau of Land Management (BLM) for the San Pedro Riparian National Conservation Area (SPRNCA), which was created in 1988 by Congress. Farming has also reduced substantially in the St. David, Benson and Pomerene areas from levels found in the 1980's.

Since 1988, additional information regarding land and water uses within the USP basin have been developed by not only the Department, but also by other state agencies, federal entities, universities, environmental groups and consortiums. This report discusses many of those studies, which also include data and analyses regarding groundwater conditions in the USP basin.

Overview of Current Water and Land Use

For the purposes of this report, the Department divided the USP basin into the "Sierra Vista sub-area" and the "Benson sub-area" (see Figure 5). These informal divisions were created by the Department to allow water use by sectors (primarily municipal and agricultural) to be discussed by geographic location. The Sierra Vista sub-area includes the portion of the USP basin from the U.S. Mexico border to Fairbank. The Benson sub-area extends from Fairbank to "The Narrows", including the Allen Flat sub-basin (see Figure 5).

Agricultural demand for the USP basin was estimated through a crop consumptive use approach to be 9,800 acre-feet in 2002, of which 7,500 acre-feet was groundwater. The agricultural consumptive use was 7,300 acre-feet in the Benson sub-area and 2,500 acre-feet in the Sierra Vista sub-area. Surface water diversions supply about 2,300 acre-feet in the Benson sub-area (see Table 2).

ADWR investigated irrigated acreage in the Benson sub-area in May 2002 and found about 2,150 acres were being irrigated at that time (Figure 3). An additional 420 acres were considered to be fallow. About 4,450 acres that were noted by ADWR in the San Pedro Hydrographic Survey Report (HSR) as being irrigated in 1991 (Arizona Department of Water Resources, 1991) were found not to be recently irrigated, based on the condition of the field and the state of repair of associated irrigation works. Site visits and aerial photo analysis of the Sierra Vista sub-area found approximately 800 acres being irrigated in 2002 (Figure 4). About 575 acres that were irrigated in 1991 are no longer irrigated (Arizona Department of Water Resources, 1991).

Municipal water use in the USP basin includes use by public and private water utilities, use at Fort Huachuca and use by domestic (exempt) wells. Basin population was estimated from the 2000 census and Department of Economic Security projections adjusted to the basin boundaries. Total basin population in 2002 was estimated at 82,400. Water delivery data was obtained from the Arizona Corporation Commission for private water companies and was adjusted to reflect pumpage by including a system loss component. Water use information was obtained directly from municipal utilities and from Fort Huachuca. The exempt well population was derived from the census data. Exempt well water use was estimated based on Tucson AMA records of large lot development use, adjusted to incorporate irrigated lands of less than 2 acres in size based on data in the San Pedro HSR (Arizona Department of Water Resources, 1991). Total municipal water use in the USP basin in 2002 was about 17,300 acre-feet, of which 16,200 acre-feet was groundwater. Municipal demand in the Benson sub-area was 3,400 acre-feet in 2002 and 13,900 acre-feet in the Sierra Vista sub-area. Effluent use in the basin in 2002 was about 980 acre-feet and surface water use was about 160 acre-feet.

Industrial water use is relatively minimal in the USP basin, consisting primarily of golf courses served by their own wells, sand and gravel facilities, a dairy and an ammonium nitrate manufacturing plant. Total industrial use was approximately 2,100 acre-feet in 2002; all of it groundwater. In 2002, industrial demand in the Benson sub-area was approximately 800 acre-feet and was 1,300 acre-feet in the Sierra Vista sub-area.

Stock watering use was estimated at about 300 acre-feet per year for the USP basin. This was estimated by geographically prorating the Cochise County stock total and using a per head, water use estimate. This demand was allocated evenly between the two sub-basins and was assumed to be groundwater.

Total municipal, industrial, agricultural and stock groundwater demand in 2002 is estimated to be about 17,300 acre-feet in the Sierra Vista sub-area and 8,800 acre-feet in the Benson sub-area for a total of 26,100 acre-feet for the basin. Natural riparian groundwater use in the USP basin is estimated at about 19,800 acre-feet per year (see Table 5). This estimate was derived from modeling studies (Jahnke, 1994; Corell and others, 1996) and from photo interpretation (Putman and others, 1988).

Figure 5 shows the number and location of well permits issued prior to 1980 by the Arizona State Land Department and the Arizona Water Commission, predecessors to the Department. Figures 6 and 7 show the number and location of well registration filings in the USP basin between 1980 and 2000, including the well permits issued prior to 1980. Not all wells that were issued registrations have been drilled (Arizona Department Water Resources, Well Registration Database, 2002).

Figure 3. Agricultural Lands in the Benson Sub-Area.

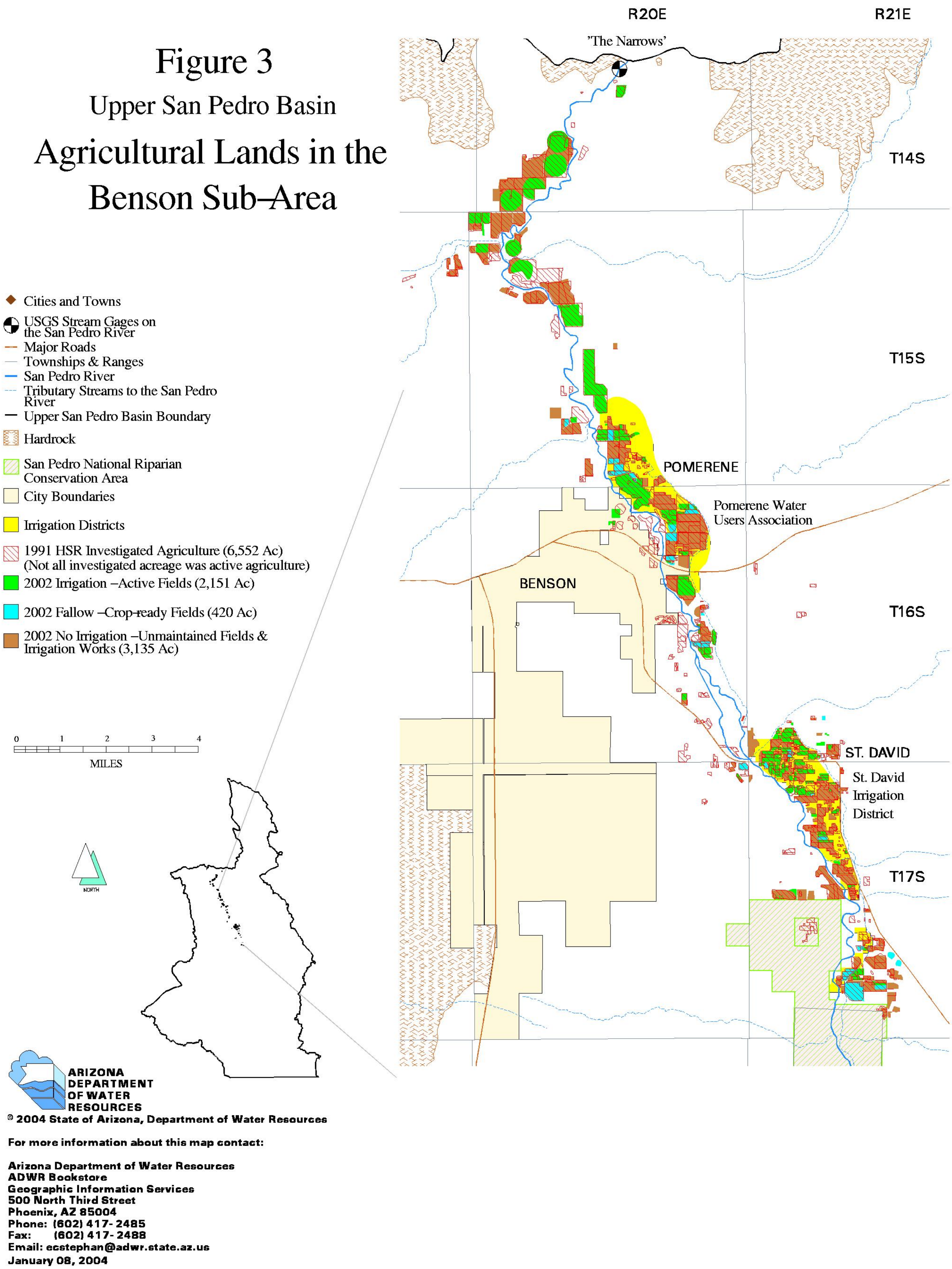


Figure 4. Agricultural Lands in the Sierra Vista Sub-Area.

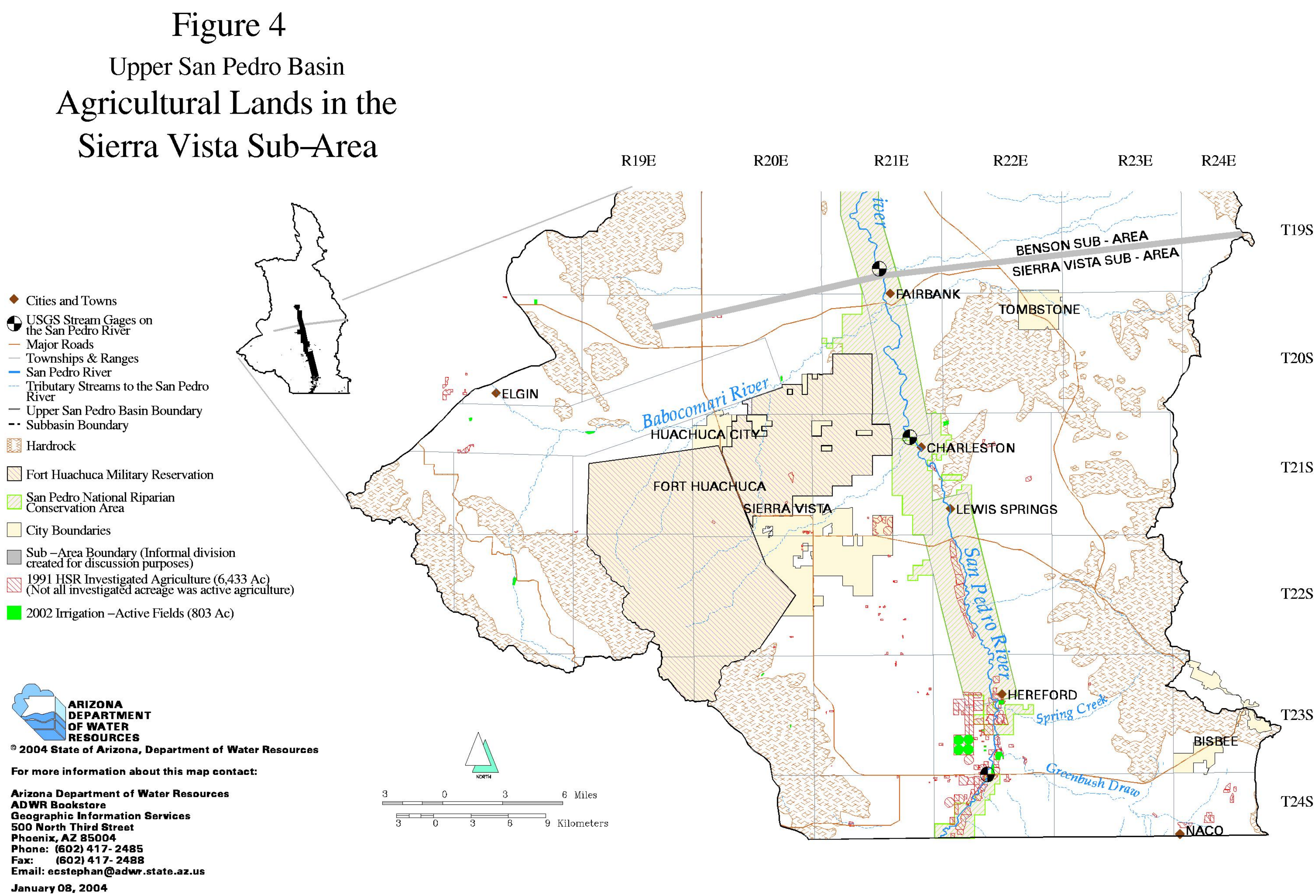


Figure 5. Well Permits Issued Prior to 1980.

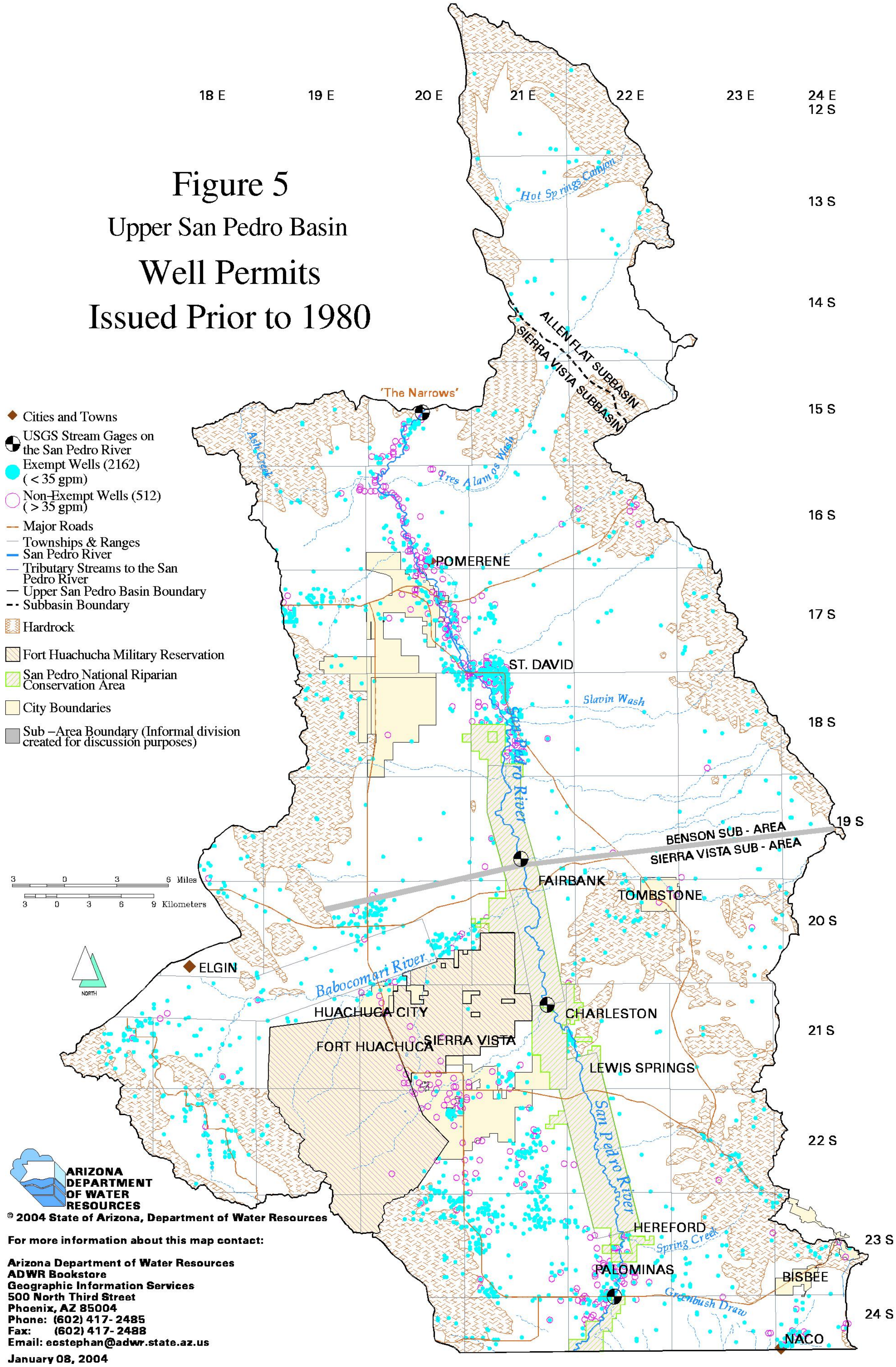


Figure 6. ADWR Well Registration Filings Issued Prior to 1990.

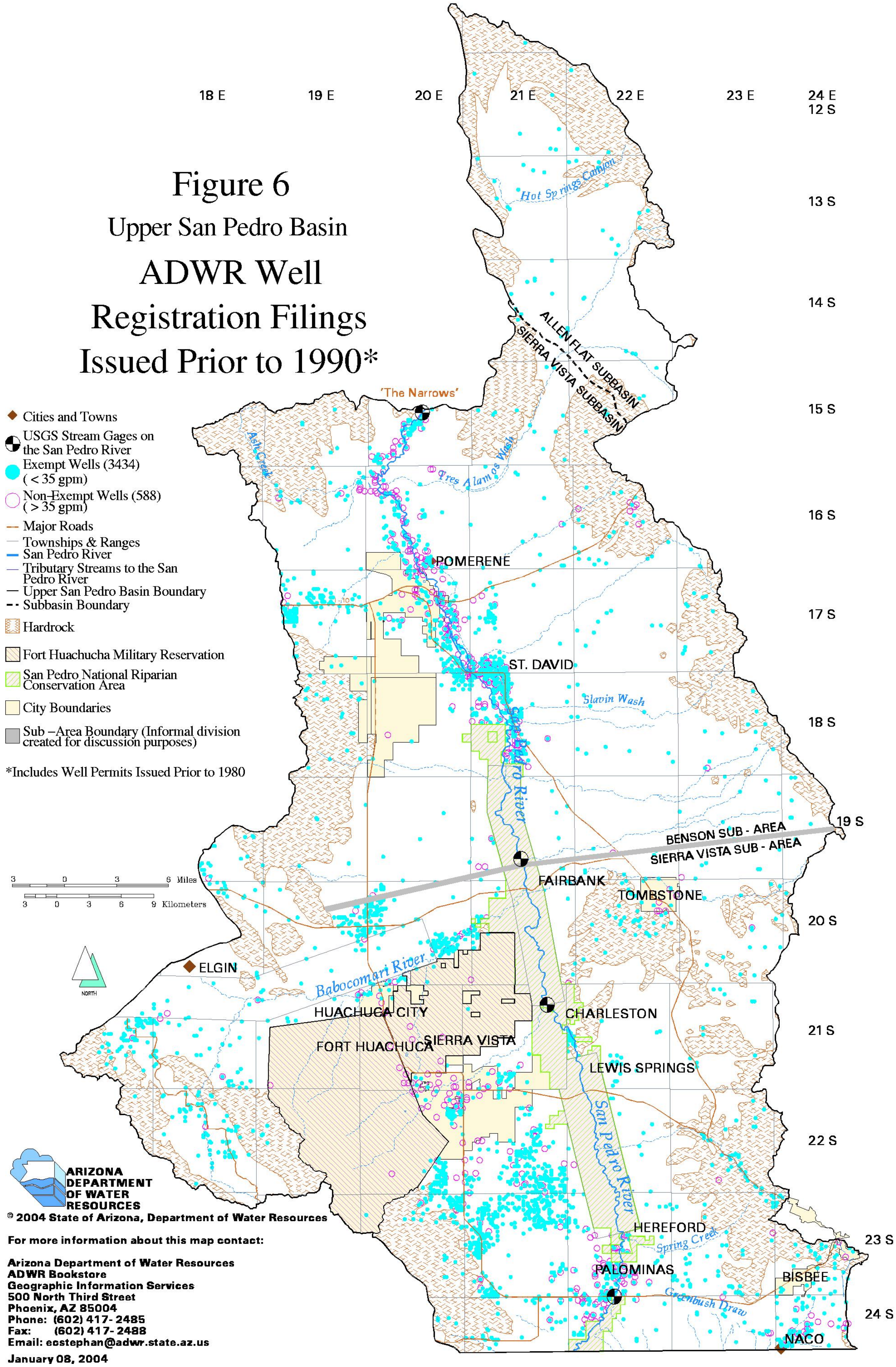
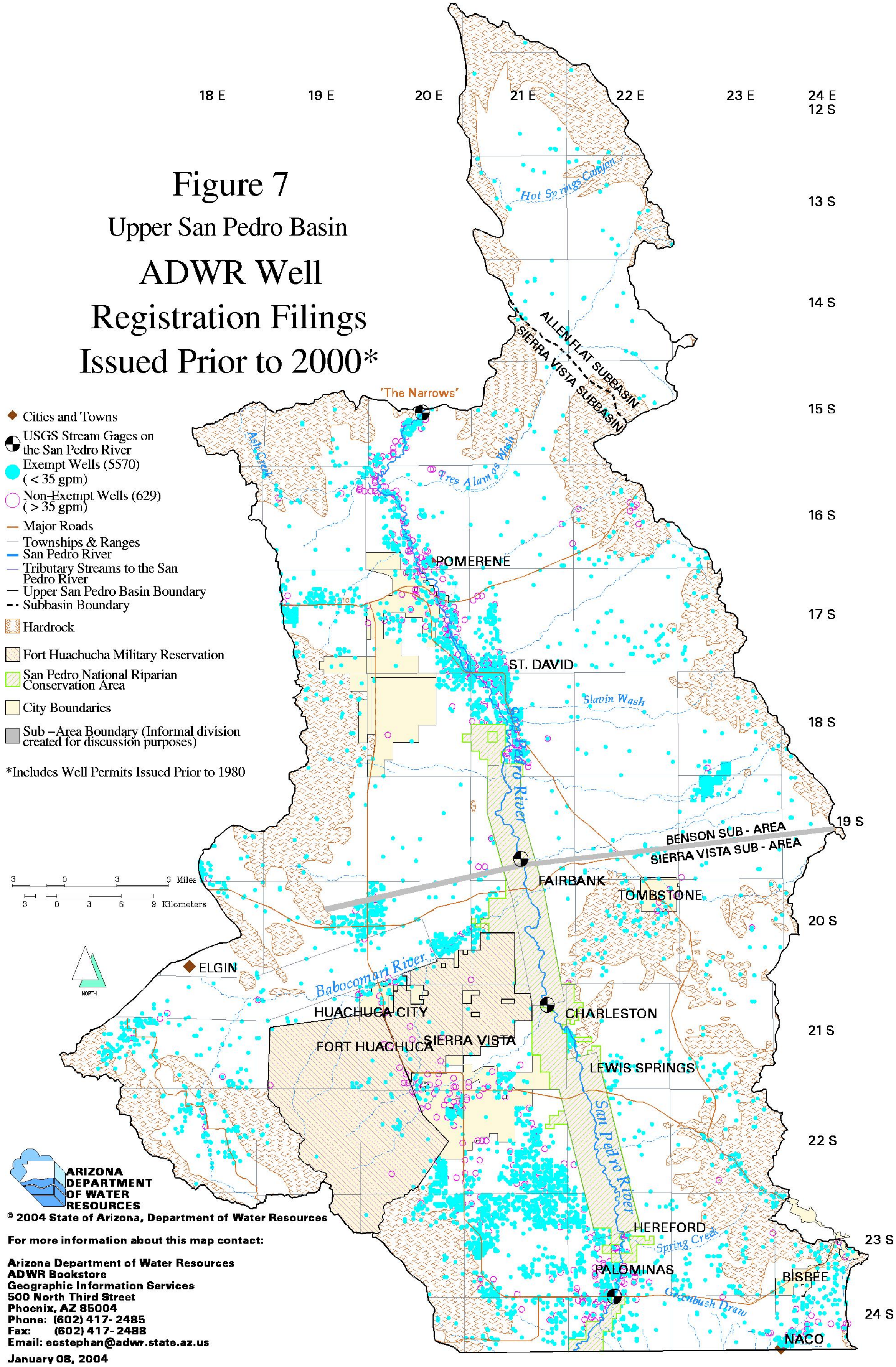


Figure 7. ADWR Well Registration Filings Issued Prior to 2000.



Basin Hydrologic Studies and Water Management Reports

The USP basin has been well studied by many state and federal agencies, including the Arizona Department of Water Resources, U.S. Geological Survey, U.S. Department of Agriculture and U.S. Bureau of Land Management. In addition, the University of Arizona and several other universities, environmental groups, and the Center for Environmental Cooperation (CEC) have conducted scientific studies of the basin. Many other studies are in progress as of the date of this report. One of the tasks of this report has been to incorporate scientific findings to date in order to make the most scientifically sound information available to Department management and the public. Scientific study has concentrated on the southern portion of the Sierra Vista sub-basin because this area is where the highest concentration of people and water use occurs in the basin.

Many geologists and hydrologists have described the groundwater system of the USP basin over the last 100 years. Lee (1905) briefly described the basin in a report to Congress. Bryan, Smith and Waring of the USGS provided an overview of the basin in 1934 (Bryan and others, 1934), discussing water use, downcutting of the floodplain, and the general hydrology. Heindl, in 1952, discussed the general hydrology of the basin and provided a regional groundwater level map. Brown and others, in 1966, discussed the geology in more detail, followed by Roeske and Werrell in 1973. The USGS provided a more detailed map of water levels, depths to water, changes in specific wells, and water quality data in 1978 (Koniezcki, 1980). In 1982, the USGS published a report on the regional hydrology of the basin that included a groundwater model (Freethey, 1982). This model was used by the Department in its 1988 evaluation of the basin for AMA status. The model was used to evaluate the effects of groundwater pumpage in the southern half of the basin (Putman and others, 1988).

The Department published its Hydrographic Survey Report (HSR) for the San Pedro River Watershed in 1991 in support of the general adjudication of the Gila River (Arizona Department of Water Resources, 1991). The HSR includes extensive data on the historic extent of farming and other water uses in the basin and the use of water by various individuals and sectors. In 1992, the University of Arizona completed a groundwater model that was based on the 1982 USGS model, but that included a more sophisticated streamflow analysis (Vionnet and Maddock, 1992). The Department published a model in 1996 that was based on re-analysis of available geologic and hydrologic data, and included a larger area of the basin within its boundaries than did the Freethey model (Corell and others, 1996). Both models deal only with the southern portion of the Sierra Vista sub-basin and not with the basin north of Fairbank. Several Masters theses that utilize groundwater models have dealt with portions of the San Pedro Basin north of Fairbank, including Jahnke (1994). Water and Environmental Systems Technology, Inc. (W&EST) has also done several groundwater models on the Upper and Lower San Pedro basin in support of water rights litigation by the Gila River Indian Community (W&EST, 1996). Goode and Maddock (2000) published a model of the entire Upper San Pedro basin that combines the model created by Vionnet and Maddock (1992) and the model created by Jahnke (1994). This model has also been used to study future effects on the groundwater system of different growth/development scenarios. Model results are discussed later in this report.

The USGS and a consortium of federal agencies and universities and agencies from the United States, France, Mexico, and other countries are engaged in ongoing and recently completed studies. An overview of these recent efforts can be found in Pool and Coes (1999) and in Goodrich (1999). The Commission for Environmental Cooperation completed a report in 1999 that listed a number of management options for the basin (Commission for Environmental Cooperation, 1999).

Other important regional studies of the basin include an evaluation of the hydrology of the Benson area by Fluid Solutions (2000), a Master's thesis set in the Allen Flat sub-basin (Burtell, 1989), and a Master's thesis on the Babocomari River (Schwartzman, 1990). In 1997, the Department produced a Hydrologic Map Series (HMS) of the USP basin showing water levels and water quality conditions in the USP basin (Barnes, 1997). Another HMS has been produced by the Department showing 2001-2002 conditions in the USP basin (Barnes and

Putman, 2004). More studies exist that deal with specific local areas of the basin and these studies are referenced in this report as necessary.

In cooperation with the Upper San Pedro Partnership (USPP), a research team was formed recently to study the San Pedro Riparian National Conservation Area (SPRNCA). The team consisted of faculty and students from the Arizona State University, the University of Arizona, and the University of Wyoming; and staff of the U.S. Department of Agriculture – Agriculture Research Service, and the U.S. Geological Survey. The study had three, primary goals – determine the water needs of riparian vegetation within SPRNCA to ensure its long-term ecological integrity; quantify the current water use by this vegetation; and, determine the source of water consumed by the vegetation. The research team collected and analyzed field data from 2000 through 2003 and summarized their findings in three, separate reports. The reports were released in draft form in March 2004 and should be finalized by early 2005 (Scott and others, 2004, in preparation).

In 2004, Congress passed the Defense Authorization Act (Public Law 108-136). Section 321 of this act directs the Secretary of the Interior to "prepare in consultation with the Secretary of Agriculture and the Secretary of Defense and in cooperation with the other members of the USPP, a report on water use management and conservation measures that have been implemented and are needed to restore and maintain the sustainable yield of the regional aquifer [in the Sierra Vista Subwatershed] by and after September 30, 2011." The '321 Report' is to be prepared annually beginning in 2004 and ending in 2011, with the first report due to Congress on or before December 31, 2004. At the time of this writing, a draft copy of the 2004 report was in final review by the Interior's Office. Included in the draft 2004 report is a description of the Upper San Pedro Basin and the Sierra Vista Subwatershed; a definition for sustainable yield; discussion of annual net withdraws and recharge in the subwatershed; a description of water-management measures to achieve sustainability; and a listing of monitoring and reporting requirements (U.S. Geological Survey, 2004a, in preparation).

CHAPTER 2 - Hydrology and Water Use

In order to determine whether the statutory criteria for designating an AMA for the USP basin have been satisfied, the Department evaluated hydrologic and water use information for the entire USP basin, as well as information specifically related to the Sierra Vista sub-basin and the Allen Flat sub-basin. For this evaluation the Department examined information relating to the existing supply of groundwater available for future needs, land subsidence and water quality. These topics are discussed below.

Existing Groundwater Supplies For Future Needs

To determine the need for an AMA, the first factor that the Department must consider is whether "active management area practices are necessary to preserve the existing supply of groundwater for future needs" (ARS § 45-412-A.1). In order to make this determination the Department evaluated geologic data, the groundwater system, historic and current groundwater levels, groundwater elevation changes, and groundwater in storage. From this data, the Department developed a groundwater budget for the USP basin. The AMA Review Report (Arizona Department of Water Resources, 2005, in preparation) discusses whether there is a need for active management area practices to preserve these groundwater supplies for future use.

Geology

Sierra Vista Sub-Basin

General basin geology is well described by Brown and others (1966). The Sierra Vista sub-basin lies between the Huachuca and Whetstone Mountains on the west and the Mule and Dragoon Mountains on the east (Brown and others 1966). Figure 8 provides an overview of the surficial extent of geologic units in the USP basin.

The Sierra Vista sub-basin is composed of several deep troughs filled with alluvial material. The bottom and sides of the sub-basin are formed by bedrock such as granite, sandstone, and limestone. These rocks lie at or near the land surface near the mountains and at depths of up to 5,500 feet below land surface in the middle of the basin (Drewes, 1980; Halverson (1984); Gettings and Houser, 2000). Gettings and Houser (2000) expanded on a gravity survey originally completed by Halverson, 1984. The Gettings and Houser study discusses three relatively deep alluvial troughs in the basin. Two of the structural troughs are located west of the San Pedro River and are north and south of Sierra Vista, respectively. The third trough is east of the San Pedro River and northwest of Tombstone. A fourth trough may exist north of Benson, but the detailed study by Gettings and Houser (2000) ends in this area, making the existence of the trough speculative. An earlier study by Oppenheimer and Sumner (1980) shows the inferred depth of alluvial fill north of Pomerene.

Figure 9 shows the regional extent of the aquifer and the depths to bedrock in the Sierra Vista sub-basin. Gettings and Houser (2000) found a more shallow area of hardrock extending between the troughs north and south of Sierra Vista. This east-west trending shallow area of hardrock under Fort Huachuca, Sierra Vista, and Charleston separates the two deep troughs to the north and south. Bedrock is found at relatively shallow depths of 200-500 feet below land surface along this line. This study also found that much of the area of the basin under the San Pedro River between Lewis Springs and Benson, was underlain by very shallow alluvium, on the order of 150 feet to 400 feet in thickness. The Gettings and Houser study is notable because it defines the depth of alluvial fill as much more shallow than prior studies, effectively reducing the estimated extent of the aquifer and the aquifer's total groundwater storage volume.

The alluvial fill of the Sierra Vista sub-basin can be divided into four general units. Pool and Coes (1999) provide a good overview of the four units. The lowermost unit is the Pantano (?) Formation, which is a consolidated conglomerate that locally supplies water to wells near Sierra Vista. The Pantano Formation yields water to wells by means of fractures in the conglomerate (secondary permeability). The Pantano (?) Formation is of several ages and is not identical in its origins to the Pantano Formation of the Tucson basin (Gettings and Houser, 2000). This unit is locally important as an aquifer, but has not been explored as a source of water regionally. The thickness of the Pantano (?) Formation ranges from 0 to several thousand feet. It outcrops on the surface to the northwest of Fort Huachuca and is found at depths of 2,000 feet or more in the alluvial troughs of the basin. The extent of the Pantano (?) Formation in the northern portion of the Sierra Vista sub-basin is not well understood. Gettings and Houser (2000) state that the Pantano (?) Formation does not outcrop north of Huachuca City and may not be present north of there. The Pantano (?) Formation forms part, but not all, of the Pre-basin and range sedimentary rocks (Tsm) shown in Figure 8.

Figure 8. Generalized Geology Map.

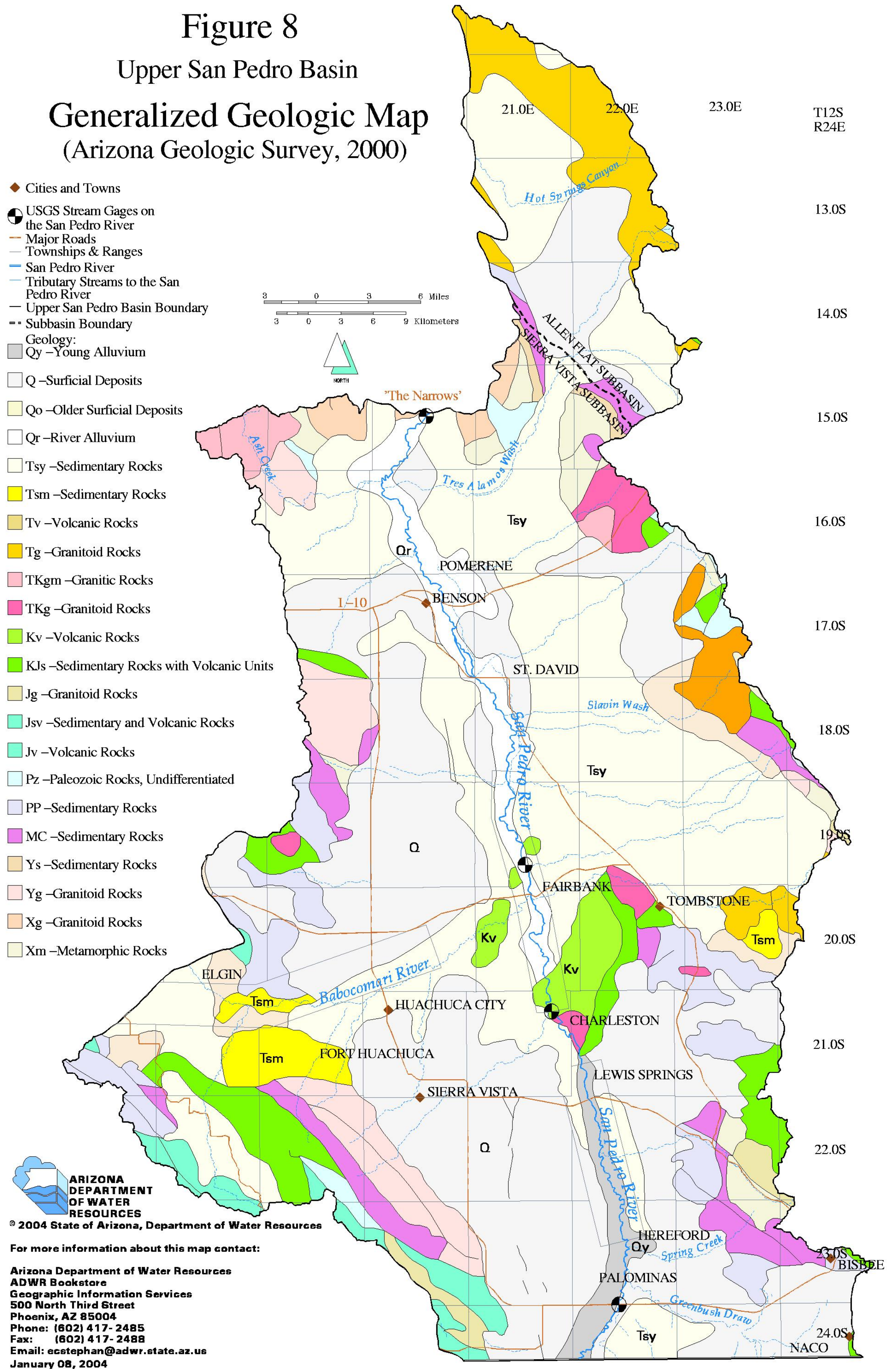


Figure 9. Depth to Top of Pantano (?) Formation.

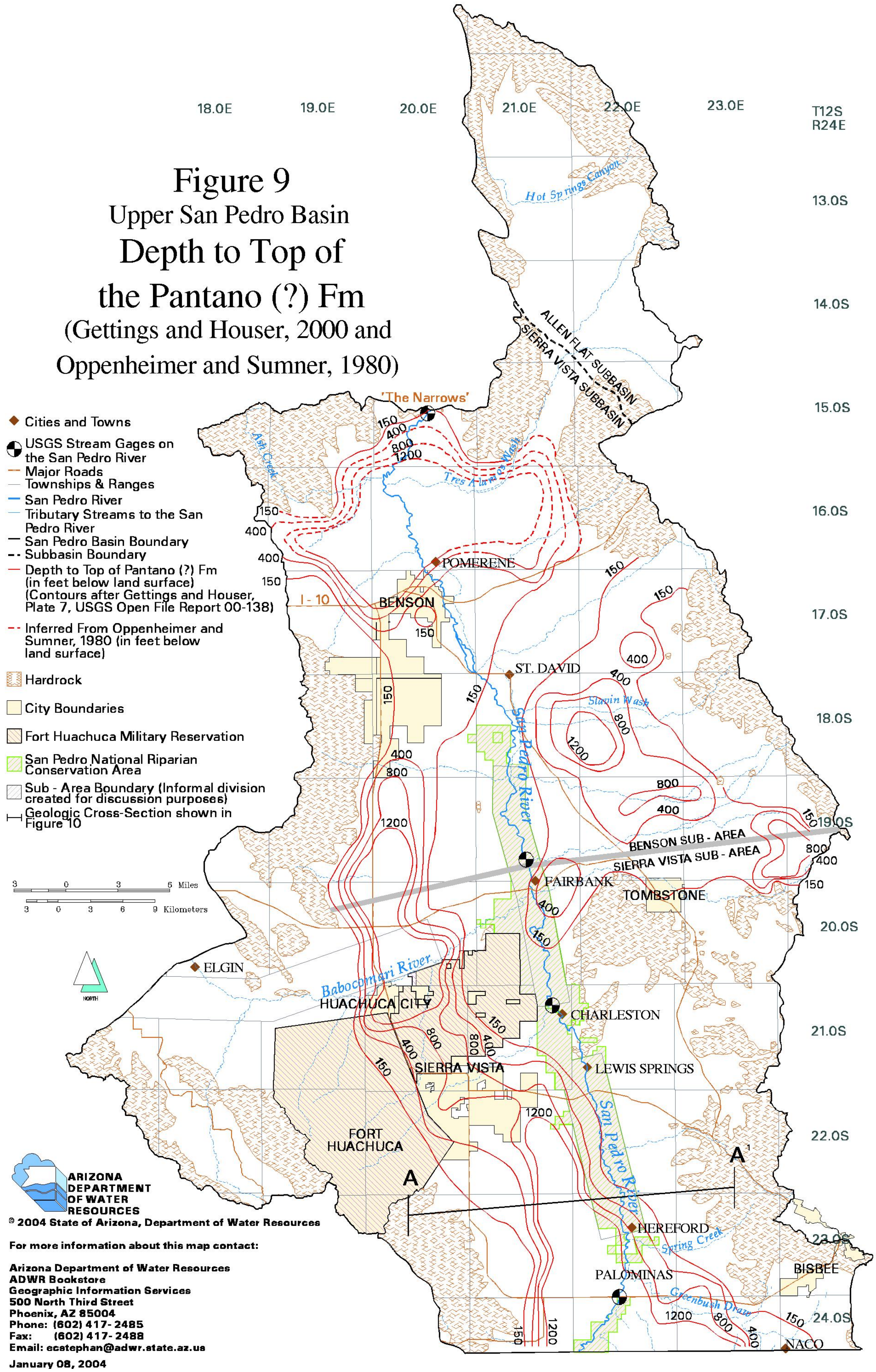
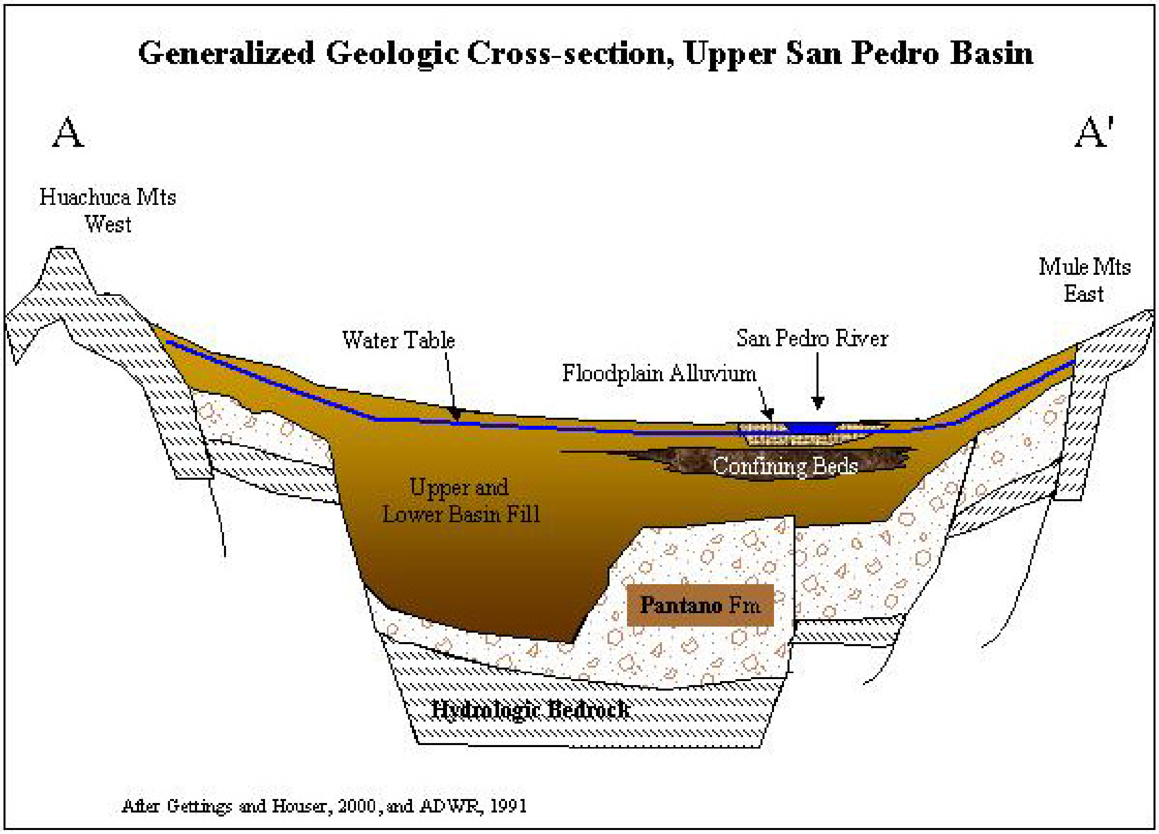


Figure 10. Generalized Geologic Cross-section, Upper San Pedro Basin.



The Pantano (?) Formation is overlain by the lower and upper basin fill units (Figure 10). The lower basin fill is the principal aquifer in much of the basin (Pool and Coes, 1999). It is more consolidated than the upper basin fill and contains a number of clay and silt lenses that may cause localized confining conditions to exist. The upper basin fill is less consolidated and contains more sand and gravels, but is not saturated in some areas of the basin. The estimated depth of the Pantano (?)-alluvium contact from Gettings and Houser (2000), together with the water levels in wells in some parts of the basin, indicate that the upper and lower basin fill units are not always saturated, and that water is being withdrawn from an underlying unit such as the Pantano (?) Formation. One such area is north of Tombstone and east of St. David.

The uppermost alluvial unit is the floodplain alluvium of the San Pedro and Babocomari Rivers. This unit is relatively thin and narrow and consists of unconsolidated gravels, sands, and silt deposited by flood flows of the river systems. It is also referred to as the recent alluvium or Quaternary alluvium. This unit is generally less than 50 feet thick and ranges in width from a few feet to about two miles (Drewes, 1980; Putman and others, 1988; Pool and Coes, 1999; Arizona Geologic Survey, 2000). It is saturated near the perennial and intermittent portions of the San Pedro and Babocomari Rivers and serves as a prolific but limited aquifer.

Allen Flat Sub-Basin

The Allen Flat sub-basin is a small, intermontane sub-basin located in the northeast portion of the USP basin (Figure 2). Allen Flat covers an area of approximately 125 square miles, roughly 25 miles in length and 5 miles wide (Burtell, 1989). The area is surrounded by several mountain ranges and small hills including the Winchester Mountains to the northeast, the Galiuro Mountains to the northwest, the Johnny Lyon Hills to the southwest, the Little Dragoon Mountains to the south, and the Steele and Gunnison Hills to the southeast. The mountain ranges listed above consist of granitic igneous and metamorphic rocks, volcanic rocks, and indurated sedimentary rocks which include limestone, sandstone, shale, conglomerate and some quartzite

(Putman and others, 1988). The majority of the basin contains basin fill that ranges from 550 to over 1,180 feet in thickness (Burtell, 1989); the maximum depth of fill is unknown. Floodplain alluvium composed of sand, gravel and some silt generally occurs along or near washes and is usually less than 25 feet in depth (Burtell, 1989).

Groundwater System

Sierra Vista Sub-Basin

There are two primary aquifers in the Sierra Vista sub-basin. They are the regional aquifer and the floodplain aquifer. The Pantano (?) Formation also serves to supply wells locally in the Sierra Vista area, but may not be regionally present (Pool and Coes, 1999; Gettings and Houser, 2000). Hydraulic communication between the upper and lower basin fill units is generally good and water levels from wells in either aquifer unit are contoured together in many areas to produce groundwater level maps for the basin. Confined conditions exist near Palominas, Hereford, and more extensively near Benson and St. David, as discussed below. The floodplain aquifer is also in good lateral hydraulic communication with the regional aquifer, and water levels in the floodplain aquifer are contoured as an extension of the regional water levels (see Figures 11 thru 16).

Several areas of confined aquifer conditions occur along the San Pedro River near St. David, Hereford and Palominas (Bryan and others, 1934; Roeske and Werrell, 1973; Konieczki, 1980; Pool and Coes, 1999). Pool and Coes (1999) described the occurrence of confined conditions as much greater than had been reported in previous studies. However, there are insufficient data to produce separate water-level maps for these confined areas. The hydraulic head in these areas has been depleted over time and the water levels in wells in confined areas may no longer rise to land surface (Roeske and Werrell, 1973). Artesian conditions were important in the early agricultural development of the St. David-Benson area and in the area north of Benson. Artesian conditions continue to support modest groundwater discharges to wells in these areas. Aquifer pressures in the confined aquifer of the Palominas-Hereford area were insufficient for large-scale irrigation (Bryan and others, 1934).

Recently the presence of a limestone aquifer in the Whetstone Mountains has been emphasized by the discovery of Kartchner Caverns, now a world-renowned state park. The cavern is a "live" or wet cave. Limestone caves also exist in the Huachuca Mountains in the southern part of the sub-basin, although they are not as extensive as Kartchner Caverns. A publication by Graf (1999) discusses the hydrology of the cave. There are three aquifer systems within the boundaries of Kartchner Caverns State Park. The southeastern part of the Park overlies the regional alluvial aquifer. The water level in a well within park boundaries that is completed in the alluvial aquifer shows that the water level in the cavern is about 700 feet higher than that of the regional aquifer. This indicates a large degree of hydraulic separation between the regional aquifer and the limestone aquifer (Graf, 1999). A pediment aquifer exists in the southwestern part of the Park. This aquifer consists of a thin layer of granitic sediment that yields water poorly to wells. The water in this aquifer is about 60 feet higher than the known bottom of the cavern. The third aquifer is the limestone formation containing the cavern. This hydrologic system is recharged by infiltration from ephemeral washes that lie over the limestone block (Graf, 1999).

Allen Flat Sub-Basin

The groundwater system of Allen Flat sub-basin is principally recharged along mountain fronts. An apparent northeast-southwest trending groundwater divide separates the sub-basin's groundwater flow system into several portions; groundwater exits the sub-basin by flowing to the west, the south and to the southwest (see Figure 15). North of the groundwater divide, the groundwater system discharges generally westward to Kelsey Canyon and Hot Springs Canyon, which are tributary to the San Pedro River north of "The Narrows" in the Lower San Pedro basin. South of the divide, groundwater flows to the south, paralleling Tres Alamos Wash, into the Sierra Vista sub-basin. Small amounts of groundwater may also flow southeast to the Willcox Playa area.

Historic and Current Groundwater Levels

Sierra Vista Sub-Basin

Groundwater elevation maps for 1940, 1961, 1968, 1978, 1990, and 2001 are presented and discussed in this report. Regional groundwater level changes and changes in specific wells are also discussed. These data were collected primarily by the USGS until about 1980, and by ADWR after that time.

For the Sierra Vista sub-area, Freethey (1982) developed a groundwater-level map representing the year 1940. This map is considered by several authors to represent a pre-development groundwater system (Freethey, 1982; Putman and others, 1988; Vionnet and Maddock, 1992; Corell and others, 1996). A pre-development groundwater system is one in which groundwater pumping has not existed or has been small enough that the groundwater flow directions and flow rates and the amount of groundwater in storage has not appreciably changed from its undisturbed, equilibrium state. The 1940 map is based on only a few data points and necessarily includes some professional judgement. This map was developed as a starting point for groundwater models and covers only the area that was modeled. Freethey's 1940 map was based on water levels in several dozen wells from the early 1950's and on annual water-level change rates. Freethey extrapolated water levels backward for a dozen years to arrive at a probable 1940 water level, and then contoured the water levels to produce a water-level elevation map for 1940 (Freethey, 1982). Corell and others (1996) used a similar procedure to develop a 1940 map for their groundwater model.

The 1940 maps of Freethey (1982) and Corell and others (1996) are similar in regional pattern. They show a groundwater flow system that receives most of its recharge near the mountain fronts and that discharges groundwater to the San Pedro River in the center of the basin. Groundwater flow is from the mountain fronts on either side of the basin toward the basin center (see Figure 11). Groundwater elevations were about 4,250 feet above mean sea level (msl) at the San Pedro River at the Mexican border and about 4,000 feet above msl near the USGS stream gage on the San Pedro River near Charleston. A feature to note is the steep water level contours at the base of the Huachuca Mountains. These water levels represent a part of the aquifer that lies above a shallow buried pediment of the Huachuca Mountains. The aquifer in this part of the sub-basin is much thinner than in the central parts of the basin, where aquifer thickness may exceed several thousand feet. Another notable feature is the absence of a cone of depression near Sierra Vista.

In 1986 the USGS published a Hydrologic Investigations Atlas that consists of three predevelopment maps as part of the Southwest Alluvial Basins, Regional Aquifer Systems Analysis Project (Freethey and Anderson, 1986). One of the goals of this project was “an overall assessment of hydrologic systems.” These maps include predevelopment water-level contours based on field data collected between the early 1900’s and 1940, historic accounts, numerical models, and recent data where long-term changes in water levels were assumed to be negligible. The water-level contours depicted for the USP basin are consistent with previous mapping. Attached as Appendix B is the part of the USGS Atlas that covers the USP basin, including the area north of Fairbank.

Brown and others (1966) published a 1961 water-level elevation map for the southernmost portion of the basin (see Figure 12). As with Freethey (1982) and Corell and others (1996), Brown’s map did not cover the area north of Fairbank. The 1961 map again shows a steeper water-level gradient along the pediment of the Huachucas, but it also shows the beginning of a cone of depression near Sierra Vista, where a decline of up to 50 feet in the groundwater level occurred between 1940 and 1961.

Roeske and Werrell (1973) published a groundwater elevation map for 1968 that covered the entire Sierra Vista sub-basin (see Figure 13). This map showed a similar flow pattern to previous water-level maps, with the aquifer being recharged near the mountain fronts and groundwater flowing laterally toward the San Pedro River in the center of the basin. Roeske and Werrell's map also showed a slightly larger and deeper cone of depression in the Sierra Vista area than Brown's 1961 map. Groundwater levels along the San Pedro River were about the same as shown by Brown. Groundwater levels near Benson were in the range of 3,450 to 3,500 feet above msl.

Konieczki (1980) published a groundwater elevation map for 1978 that also showed the entire Sierra Vista sub-basin (see Figure 14). Konieczki's map again showed a steeply-sloping water table along the Huachuca Mountain pediment and a similar cone of depression to that of Brown (1966) and Roeske and Werrell (1973). Hydrographs of water-level changes in wells studied by Konieczki (1980) showed annual decline rates of up to 4 feet per year near Sierra Vista and decline rates of 0 to 0.7 feet per year in other parts of the basin. By 1986, a few parts of the basin showed water-level rises (Putman and others, 1988). Water levels in wells along the San Pedro River remained largely unchanged.

The Department began collecting extensive groundwater data throughout Arizona in 1980. Quarterly and annual water-level data is collected routinely by the Department in the USP basin through its index well program. In 1997, the Department published a water-level map for 1990 (Barnes, 1997). In 1989, Burtell published a Master's thesis that covered the Allen Flat sub-basin of the USP basin. The water-level data from these two reports have been combined as Figure 15.

Figure 15 shows a cone of depression in the Sierra Vista sub-area and a more disturbed groundwater flow pattern in that area than previously shown. Undisturbed groundwater flowpaths are generally smooth and without sharp bends in elevation contour lines. The 1990 map shows sinuous water-level contour lines in the Sierra Vista area, indicating the influence of pumping wells on the water table.

During the winter of 2001-2002 the Department collected water levels in the entire basin in support of the present study (Barnes and Putman, 2004). These water levels are shown in Figure 16 and show that the general pattern of groundwater flow remained unchanged from 1990. The cone of depression near Sierra Vista is essentially of the same size and location, but has deepened slightly. A very small cone of depression is developing along Greenbush Draw, between Naco and the San Pedro River. This area is used to supply water from wells to Bisbee. Water levels near Benson and Pomerene have risen, possibly in response both to less groundwater demand for farming and to recharge from flood flows of the San Pedro River, particularly the October, 2000 flood event. Pool and Coes (1999) published a 1998 water-level elevation map for the southern portion of the Sierra Vista sub-basin. The 1998 map covers the area south of Fairbank and compares closely with the 2001-2002 data collected by the Department.

Figure 17 shows the approximate depth to the regional water table, in feet below land surface. Small areas of perched groundwater exist in the basin. Depth to groundwater will be less in these areas.

Allen Flat Sub-Basin

Depth to groundwater in the Allen Flat sub-basin ranges from less than 10 feet near washes to more than 600 feet near the mountains (Arizona Department of Water Resources, 2002, GWSI). Burtell's thesis provides more information on this sub-basin (Burtell, 1989). Figure 15 shows water level data reported by Burtell (1989). Water-level data collected by the Department in 2001-2002 was insufficient to contruct a detailed groundwater elevation map for the Allen Flat sub-basin. No significant changes in groundwater elevation are expected given that groundwater development within the Allen Flat sub-basin has been negligible.

The majority of the wells in the Allen Flat sub-basin are drilled into the basin fill. Burtell (1989) reported thick basin fill units near the edge of the basin; four wells penetrated 550 to 1,180 feet of alluvium within one mile of exposed bedrock. Well depths throughout the sub-basin range from 20 feet to over 1,300 feet and well yields range from 1 to 35 gpm (Burtell, 1989; Arizona Department of Water Resources, Well Registration Files, 2002).

Figure 11. 1940 Groundwater Elevations.

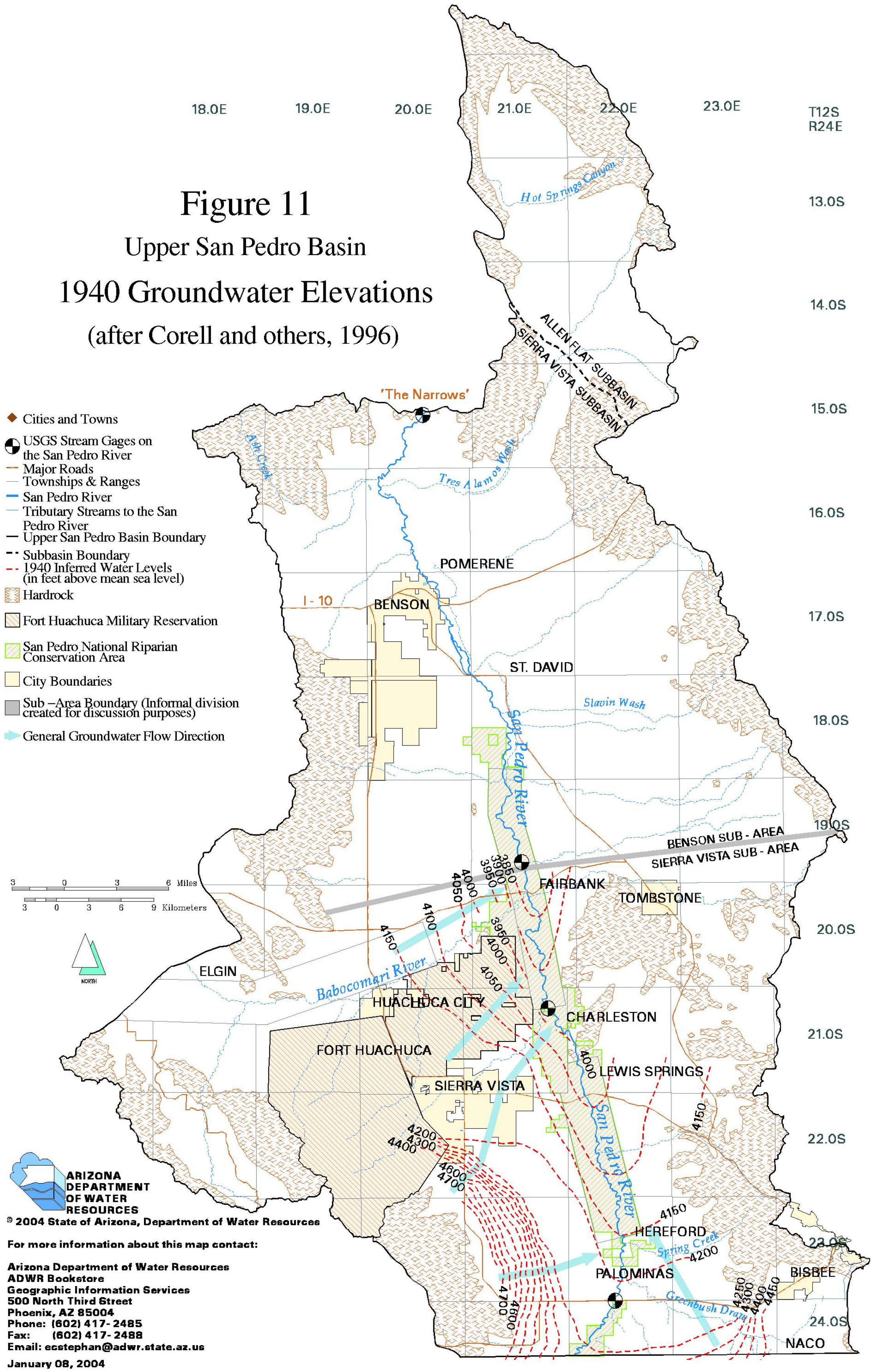


Figure 12. 1961 Groundwater Elevations.

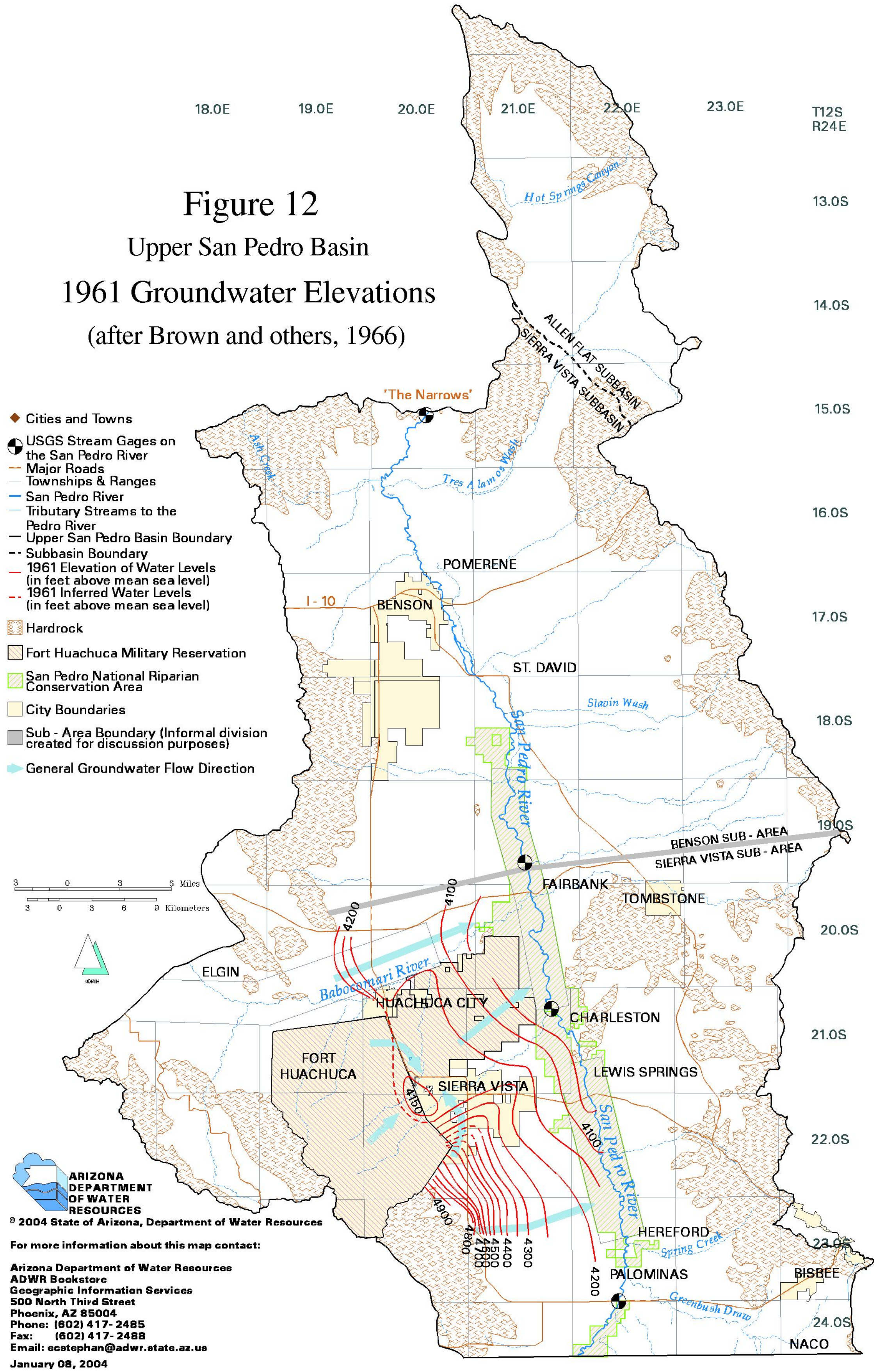


Figure 13. 1968 Groundwater Elevations.

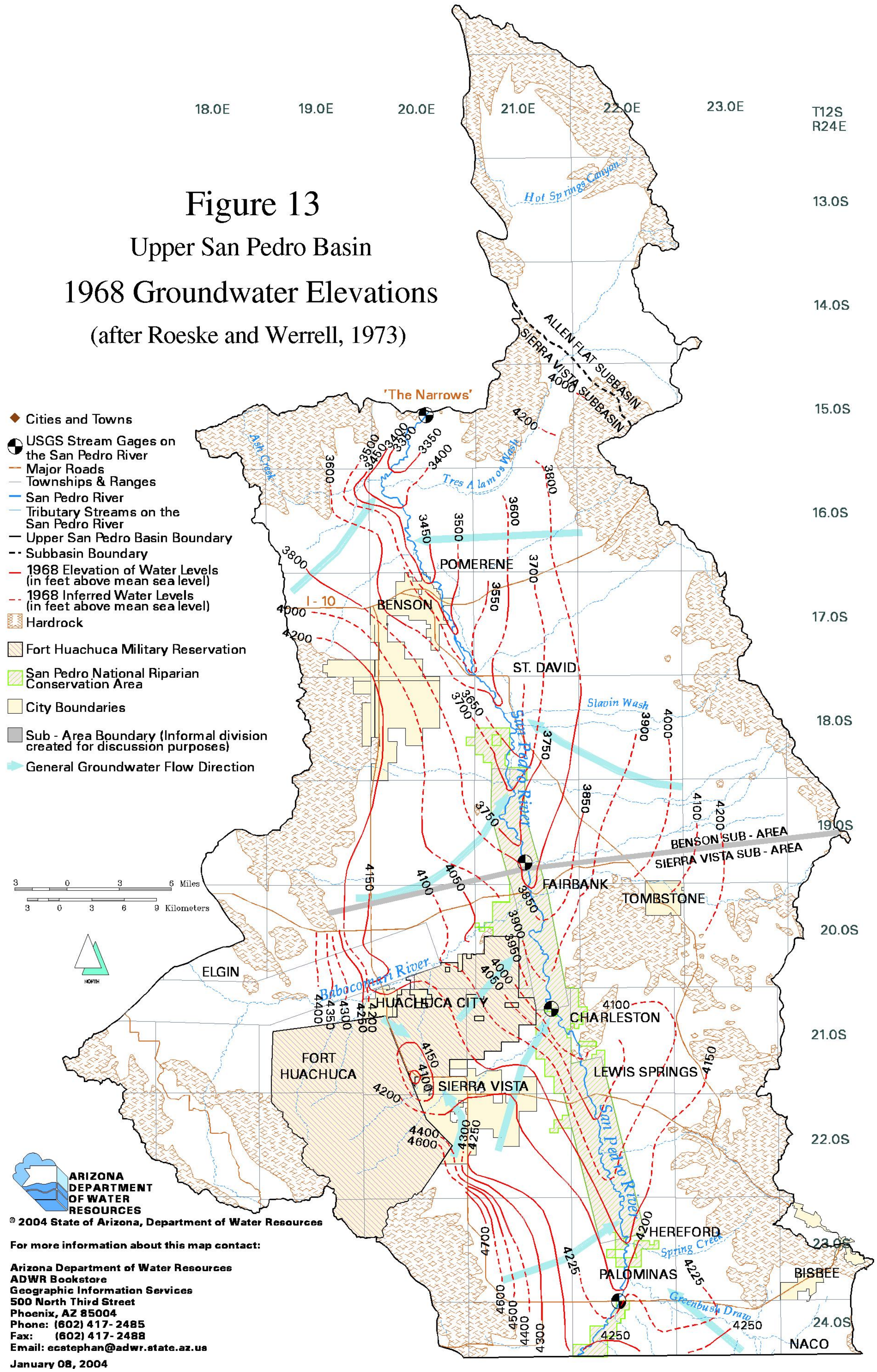


Figure 14. 1978 Groundwater Elevations.

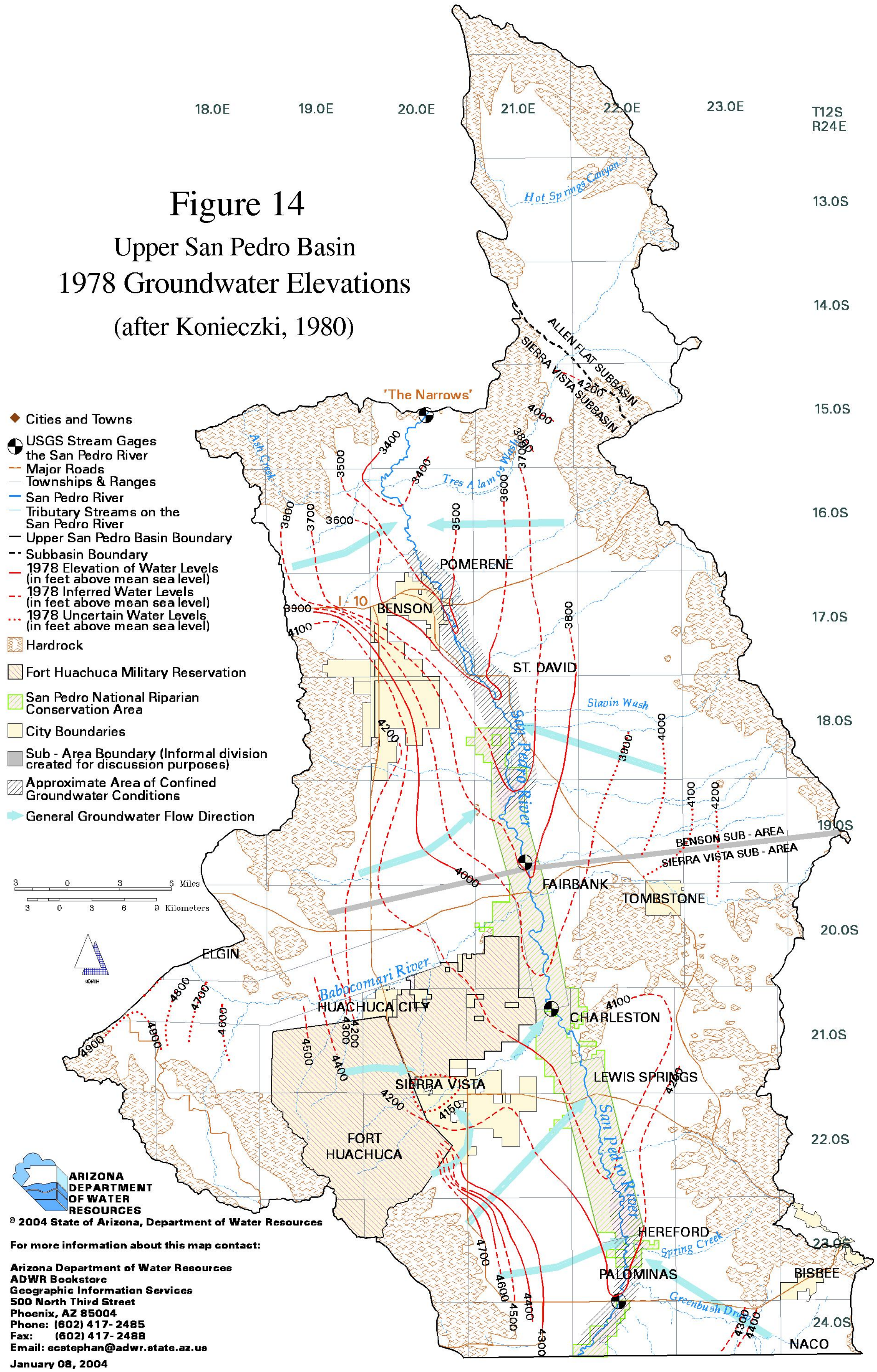
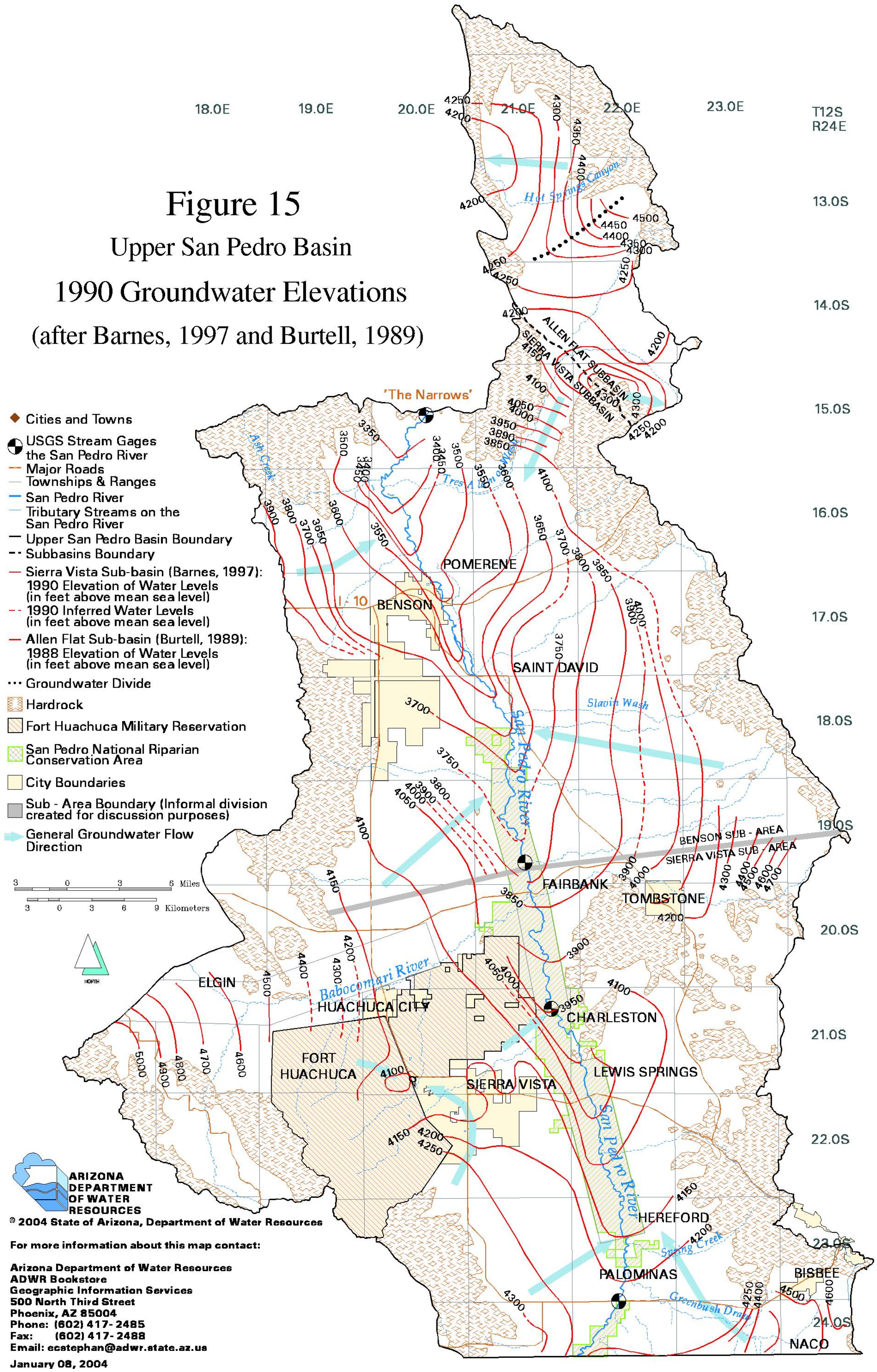


Figure 15. 1990 Groundwater Elevations.



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Fax: (602) 417-2488
Email: ecstephan@adwr.state.az.us

January 08, 2004

Figure 16. 2001 Groundwater Elevations.

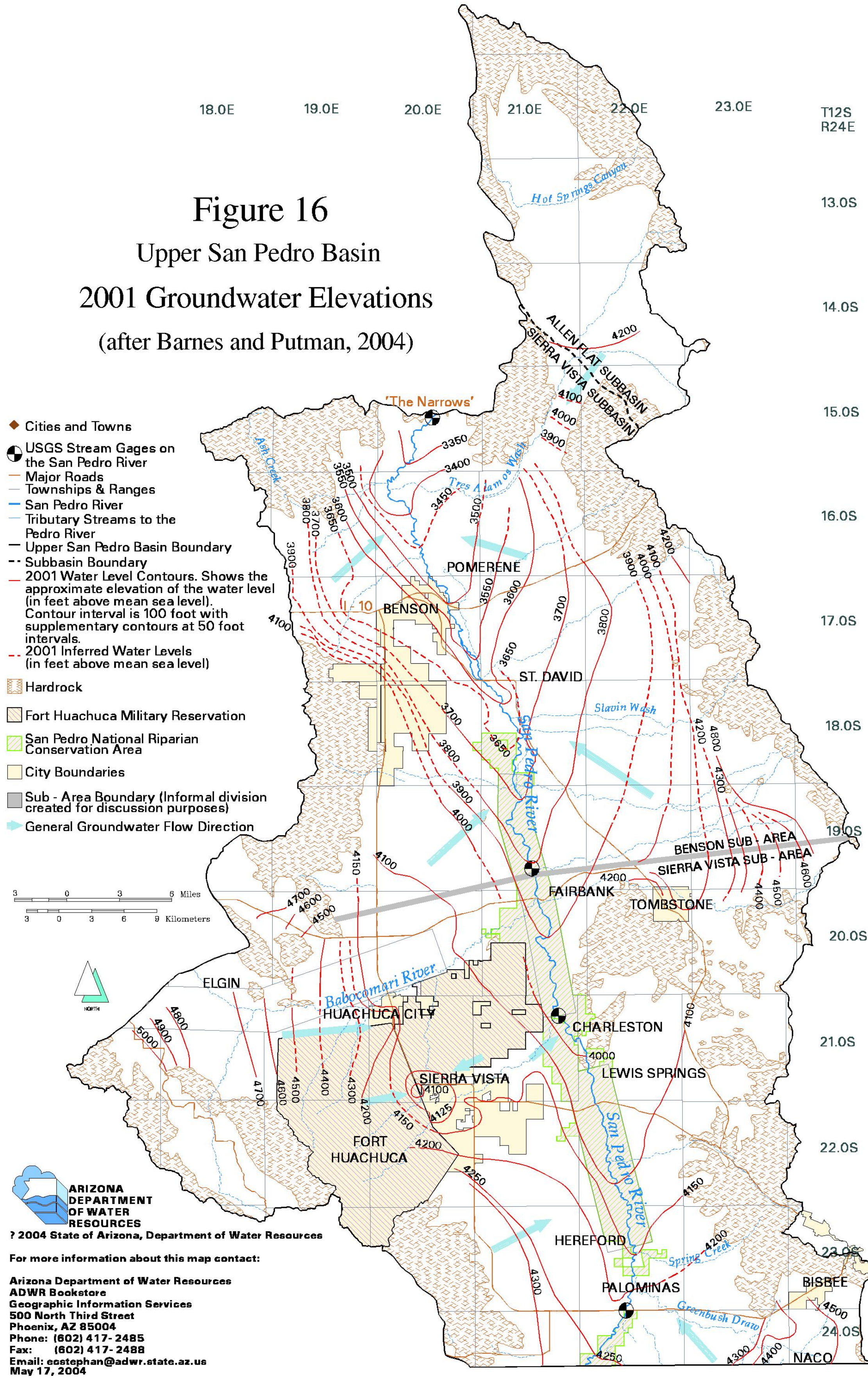
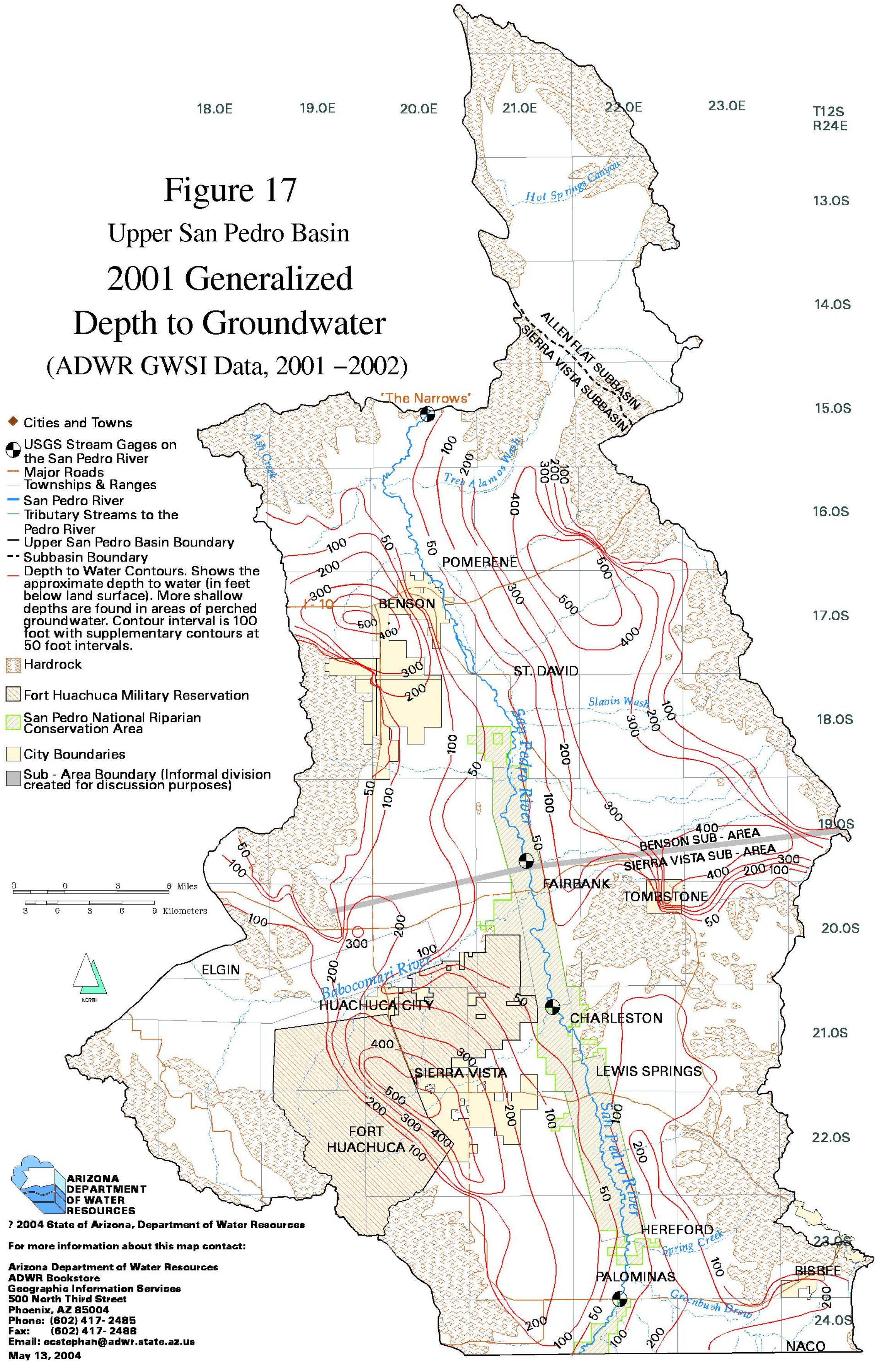


Figure 17. 2001 Generalized Depth to Groundwater.



Groundwater Elevation Changes

Basin-wide changes in groundwater levels between 1990 and 2001 are shown in Figure 18, along with the location of representative well hydrographs. Figure 19 shows the water-level hydrographs for these representative wells (Barnes and Putman, 2004) which are described by general geographic location and cadastral number (see Appendix C for a description of well numbering system). Hydrographs are charts that show water levels or depths to water in a single well over a period of time. The hydrographs are useful in understanding the changes in the aquifer system in localized parts of the basin.

Sierra Vista Sub-Basin

In the Sierra Vista sub-basin, reasons cited for changes in water levels include pumping, recharge, climatic change (Pool and Coes, 1999) and a regional adjustment associated with downcutting of the San Pedro River that began near Winkelman in 1883 and progressed upstream over the next several decades (Bryan and others, 1934, and Brown and others, 1966). Water-level changes have not been extreme for a large part of the Sierra Vista sub-basin. Most of the hydrographs shown in Figure 19 show a slight downward trend over many years. A few hydrographs show steeper downward trends, particularly in the Sierra Vista-Ft. Huachuca area where water-level declines have been historically noted. The area between Bisbee and Naco shows unexpected changes, with the largest declines in the sub-basin from 1990 to 2001 (Barnes and Putman, 2004). Following is a discussion of water-level changes within specific areas of the sub-basin for the 11-year period from 1990 through 2001.

The Narrows – North of Pomerene

Just south of "The Narrows", water-level changes ranged from a rise of 0.1 foot to a decline of 5.3 feet, with an average decline of 1.5 feet. Wells measured along the San Pedro River, north of Pomerene had water-level changes ranging from 0 to a maximum rise of 11.1 feet, with an average rise of 4.7 feet (Barnes and Putman, 2004). Most wells in this area are shallow.

Pomerene - Benson

Moderate water-level declines were recorded in both the shallow aquifer and deeper regional (artesian) aquifer in the Pomerene –Benson area. Water-level changes in the shallow aquifer ranged from a rise of 0.5 feet to a decline of 10.2 feet, with most declines in the 1.0 to 5.0 foot range. Changes in deep wells ranged from a rise of 0.3 feet to a decline of 18.9 feet, with most declines in the 4.0 to 9.0 foot range (Barnes and Putman, 2004). West of Benson along Interstate 10, water-level declines ranged from 5.0 to 7.0 feet, with a maximum decline of 11.8 feet. A cone of depression appears to be forming in this area in the vicinity of a municipal wellfield.

St. David

In the St. David area, a large number of wells are completed in the shallow aquifer and a large number are completed in the deeper, regional (artesian) aquifer. Water-level changes ranged from a rise of 12.9 feet to a decline of 11.1 feet. In the shallow aquifer south of St. David, recorded declines in water-levels were about 1 foot per year. Wells completed in the regional aquifer showed the least amount of change; several wells reflected a rise in water level of up to 5 feet (Barnes and Putman, 2004).

Sierra Vista-Huachuca City-Nicksville

Water-level declines in the Sierra Vista area have been historically noted and have continued to decline from 1990 to 2001. Declines in water-levels in and around Sierra Vista range from 1.2 feet to 14.8 feet in a public supply well. This public supply well has a recorded average water-level decline of 1.4 feet per year for the period 1990-2001. Most wells within the cone of depression have water-level declines of less than 1 foot per year. The depression has been generally expanding in an east-southeasterly direction from the deepest part of the cone. Hydrographs K, L, M and O show the steady decline in water levels within the cone of depression (Barnes and Putman, 2004).

North of Sierra Vista, water-level declines became less pronounced for the period 1990-2001 than in prior years. Between Sierra Vista and Huachuca City, water-level declines between 5.0 feet and 7.0 feet were recorded; north of Huachuca City, recorded declines were between 1.0 feet and 5.0 feet. A public supply well in this area had a water-level decline of 13.4 feet (1.22 ft/yr) since 1990 (Barnes and Putman, 2004).

South of Sierra Vista, near Nicksville, a wide range of declines and rises have occurred since 1990. Water-level declines ranging from 26.4 to 35.4 feet have been recorded. Closer to the foothills of the Huachuca Mountains, water levels become more varied ranging from a decline of 8.7 feet to a rise of 16.6 feet; these extreme fluctuations are shown on Figure 18. Many of the wells near the mountains are completed on the pediment in fractured hardrock and are more susceptible to rainfall or drought conditions than wells completed in the regional aquifer (Barnes and Putman, 2004).

<u>Tombstone</u>
Water-level declines in the Tombstone area range from less than 1 foot to 23 feet. Many of the declines are in shallow, windmill wells located near washes. Three deep (600-890 feet) public supply wells had declines ranging from 3.3 feet to 23.1 feet (Barnes and Putman, 2004).

<u>Naco</u>
The sharpest water-level declines in the USP basin have occurred in the Naco area, with declines ranging from 9.8 feet to 32.1 feet. Toward the San Pedro River to the west, water levels ranged from a rise of 1.0 foot to a decline of 4.1 feet (Barnes and Putman, 2004).

<u>International Boundary – Hereford</u>
South of Hereford to the United States-Mexico International Boundary, water-level changes have ranged from a rise of 7.0 feet to a decline of 4.9 feet, with most wells showing changes of +/- 3.0 feet.

Allen Flat Sub-Basin

Very little change in water levels has occurred in the Allen flat sub-basin. Hydrographs were constructed from two wells located near Tres Alamos Wash in the Allen Flat sub-basin and are shown as A and B on Figure 18. Hydrograph A for well (D-14-21) 11BBC shows a slight water-level rise of 0.1 feet per year from 1968 through 2001. Hydrograph B for well (D-14-22) 34BDC shows a water-level decline of 0.6 feet per year from 1968 through 2001 (Figure 19). Data were not available to construct hydrographs for other wells in the sub-basin.

Figure 18. Well Hydrograph Locations and Groundwater-Level Changes, 1990-2001.

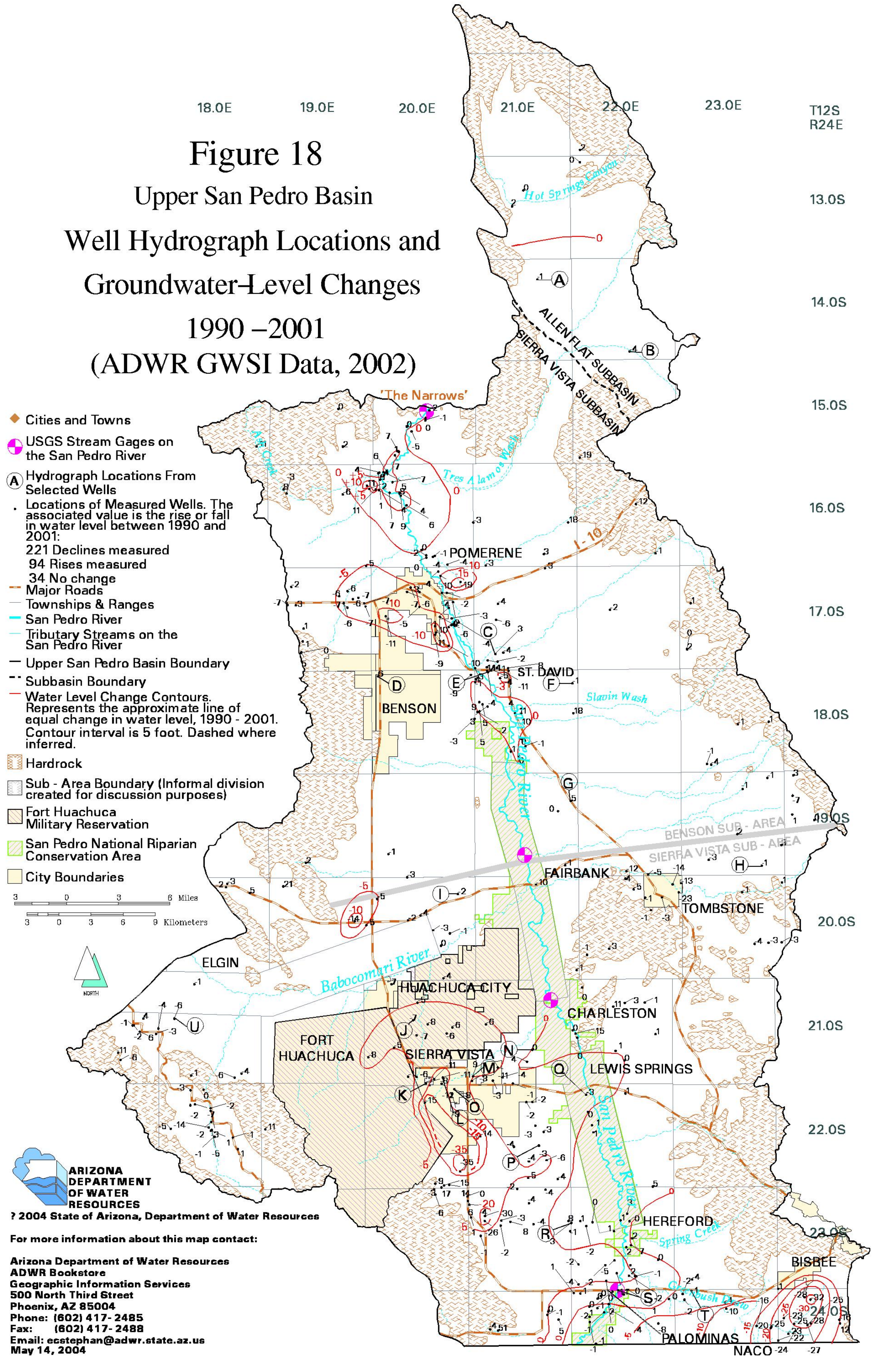
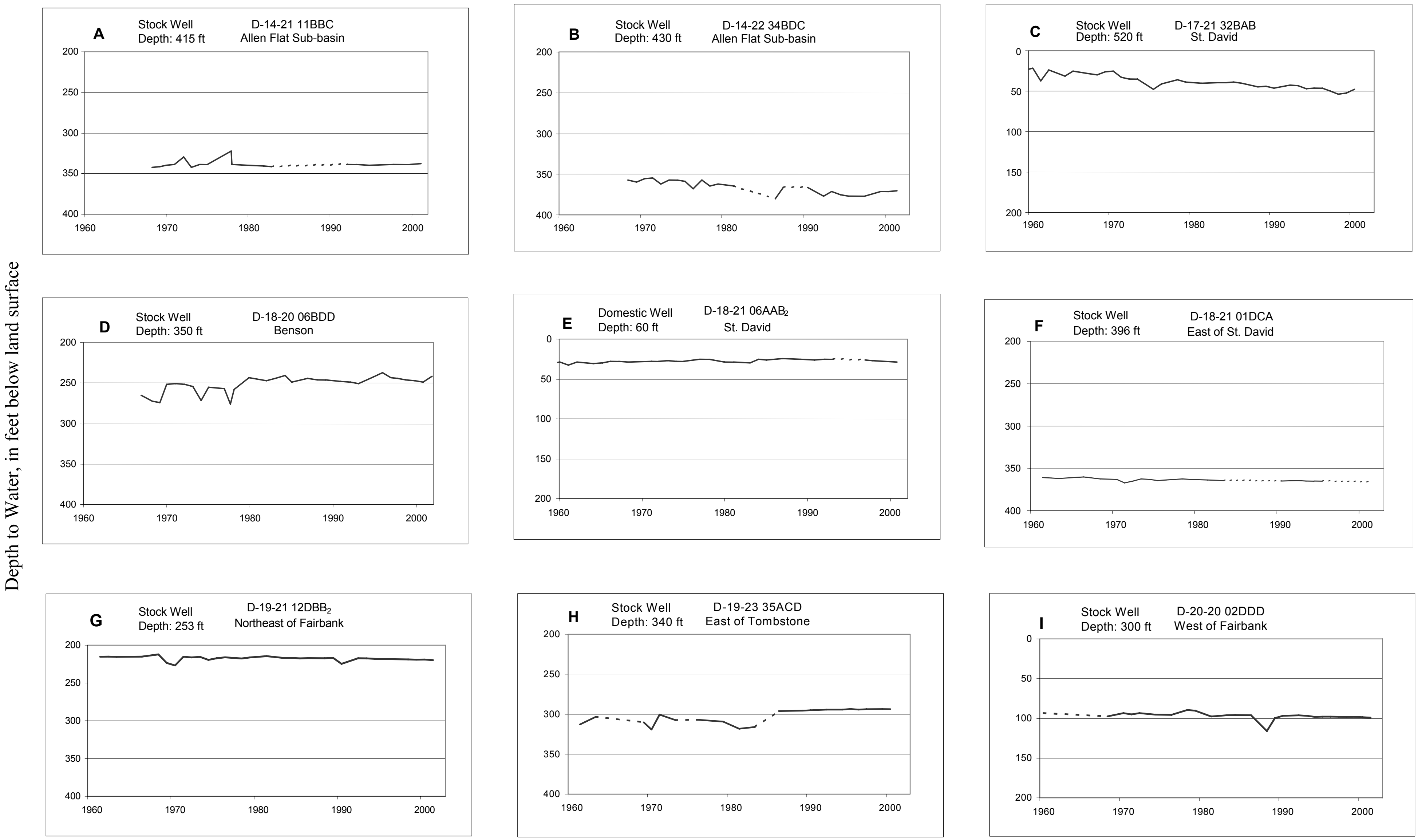
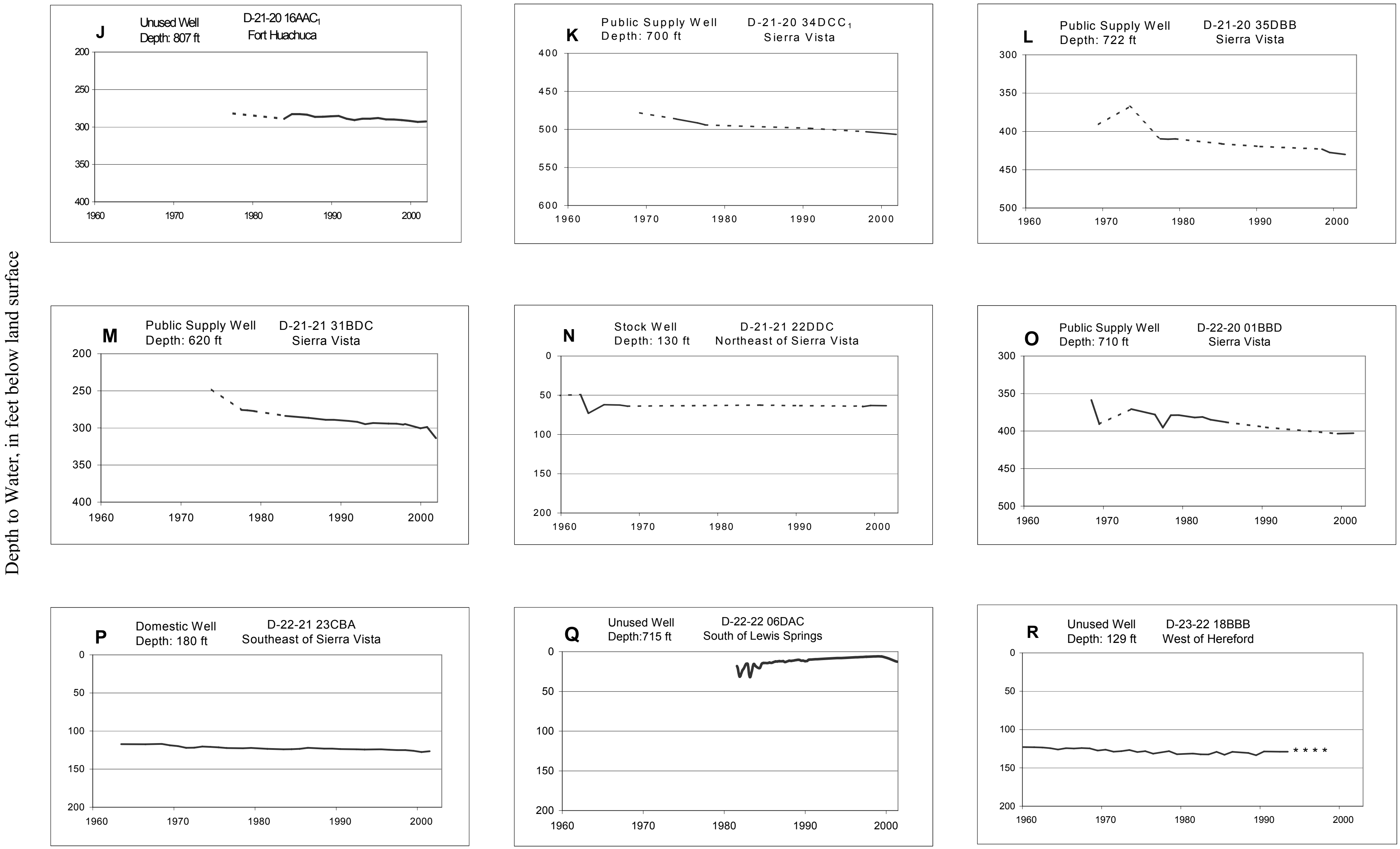
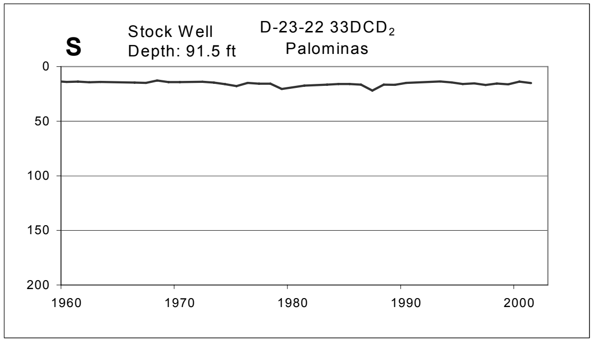
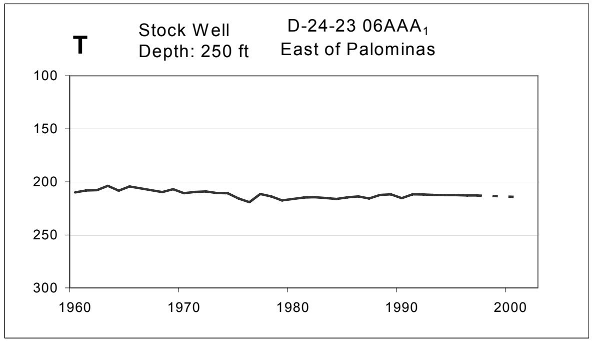


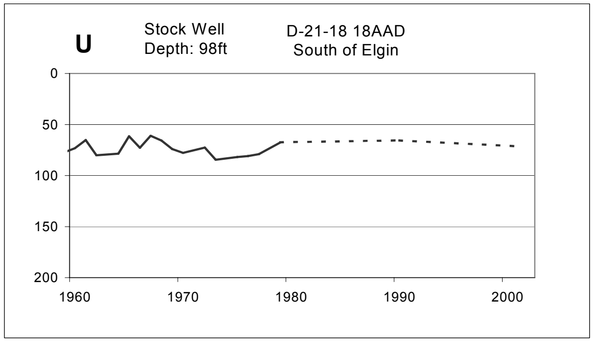
Figure 19. Hydrographs of Water Levels in Selected Wells.




Depth to Water, in feet below land surface
J
Unused Well
Depth: 807 ft
D-21-20 16AAC1
Fort Huachuca
K
Public Supply Well
Depth: 700 ft
D-21-20 34DCC1
Sierra Vista
L
Public Supply Well
Depth: 722 ft
D-21-20 35DBB
Sierra Vista
M
Public Supply Well
Depth: 620 ft
D-21-21 31BDC
Sierra Vista
N
Stock Well
Depth: 130 ft
D-21-21 22DDC
Northeast of Sierra Vista
O
Public Supply Well
Depth: 710 ft
D-22-20 01BBD
Sierra Vista
P
Domestic Well
Depth: 180 ft
D-22-21 23CBA
Southeast of Sierra Vista
Q
Unused Well
Depth:715 ft
D-22-22 06DAC
South of Lewis Springs
R
Unused Well
Depth: 129 ft
D-23-22 18BBB
West of Hereford
1960
1970
1980
1990
2000







Note: Asterisk indicates a dry well.

Dashed line indicates an inferred water-level.

Groundwater in Storage

An estimate of the amount of groundwater stored in the regional and floodplain aquifers within the Sierra Vista sub-basin was made for this study by the Department. Data used were water levels collected by the Department in winter, 2001-2002 (Arizona Department of Water Resources, GWSI data, 2002), depth to Pantano (?) Formation and depth to bedrock maps from Gettings and Houser (2000) and Oppenheimer and Sumner (1980). Estimates of aquifer specific yield were from Corell and others (1996) and from literature surveys. Groundwater in storage was not estimated for the Allen Flat sub-basin given the paucity of data for this area.

In the upper and lower basin fill, the Department estimated that about 15.6 million acre-feet of groundwater remain in storage within the Sierra Vista sub-basin. In the upper and lower basin fill, a specific yield of 8% was used for this estimate (Corell and others, 1996), and the volume of basin fill considered was the portion between the water table and either hydrologic bedrock or the Pantano (?) Formation, or 1,200 feet below land surface if the basin fill extended deeper than this distance. Figure 9 (Depth to Top of Pantano (?) Fm) was used to estimate basin fill thickness. The Department does not consider water at depths below 1,200 feet to be economically recoverable, and uses this depth as its cut-off for useful aquifer storage depth. This storage estimate is less than previous estimates because new data from Gettings and Houser (2000) show that the thickness of alluvium is substantially less in some areas than previously thought by other researchers. The Gettings and Houser study estimated the thickness of basin fill and depth to bedrock using a sophisticated procedure involving interpolation of a residual gravity anomaly grid and stratigraphic data.

The Pantano (?) Formation is a conglomerate that underlies the basin fill, and most of its water is probably yielded to wells through fractures in the conglomerate (Pool and Coes, 1999). Gettings and Houser (2000) mapped the depth to the top and bottom of a sedimentary unit underlying the basin fill in most of the Sierra Vista sub-basin. South of Huachuca City, Gettings and Houser (2000) identified this unit as the Pantano (?) Formation. North of Huachuca City, Gettings and Houser did not confirm the identity of the underlying unit. The volume of groundwater storage in the Pantano (?) Formation between the basin fill and a depth of 1,200 feet below land surface was estimated at 3.8 million acre-feet using a specific yield of 3% and depth to bedrock information from Gettings and Houser (2000). This specific yield value of 3% was based on a literature review of values for fractured rocks (Davis and DeWiest, 1966; Fetter, 1994; Walton, 1970). Corell and others (1996) modeled the Pantano (?) using a specific yield of 8%, which allows an estimate of water in storage of about 10.1 million acre-feet. The Pantano (?) Formation is largely unexplored in the basin and the estimate of water in storage is subject to re-evaluation when more data are available.

The floodplain aquifer of the USP basin is a shallow and narrow shoestring aquifer, which is quite productive but limited in the amount of groundwater it can store. Groundwater in storage was estimated at 421,000 acre-feet (Putman and others, 1988).

Total groundwater storage in the Sierra Vista sub-basin was estimated between 19.8 million and 26.1 million acre-feet. This range is considerably less than the 41 million acre-feet of storage estimated in ADWR's HSR (1991) and the estimate of 48 million acre-feet cited by Putman and others (1988). The difference comes from re-definition of the depth to bedrock by Gettings and Houser (2000), and from use of lower specific yield estimates. The estimate of 48 million acre-feet cited in Putman and others (1988), was taken from a 1975 report by the Arizona Water Commission (1975), which in turn cited unpublished data from the USGS.

Groundwater Budget

A groundwater budget is an accounting of inflows into an aquifer and outflows from an aquifer. The difference between the two results is a change in groundwater in storage. The difference is not constant from year to year, but over a long period of time can indicate if a groundwater system is in an overdraft situation. The Department developed a groundwater budget for the USP basin by examining inflows and outflows in the groundwater system in the Sierra Vista sub-area and the Benson sub-area. As previously mentioned, the Sierra Vista sub-area and the Benson sub-area are informal divisions of the USP basin. The divisions were created by the Department for discussion purposes to allow the water uses in the sub-basin to be grouped into use sectors (primarily municipal and agricultural) and by geographic location. The Benson sub-area includes the Allen Flat sub-basin.

Inflows

Major inflows into the groundwater system come from recharge of water along the fronts of the Huachuca, Mule, Whetstone, Rincon and Dragoon Mountains (including ephemeral channel recharge), from groundwater flowing across the Mexican Border, and from recharge of flood flows of the streams in the basin. Secondary sources are recharge of water from recharge projects, septic tanks, and golf courses.

<u>Sierra Vista Sub-Area</u>
Mountain front recharge estimates are available from Corell and others (1996), from ADWR's HSR (1991), from Anderson and Freethey (1994), and from Goode and Maddock (2000). Estimates for the Sierra Vista sub-area of the Sierra Vista sub-basin are believed to be more accurate than for the Benson sub-area because of the many studies that have taken place in the southern part of the USP basin. Estimates for the Benson sub-area are more generalized and less precise.

Corell and others (1996) estimated that a total of 19,000 acre-feet per year recharged the groundwater system of the Sierra Vista sub-area. This included mountain front recharge and ephemeral stream channel recharge, including 1,000 acre-feet of recharge along Greenbush Draw (Corell and others, 1996), and about 3,000 acre-feet per year of groundwater flux from Sonora to Arizona. This mountain front recharge and ephemeral stream recharge estimate was derived from baseflow records of the San Pedro River at the Palominas, Charleston, and Tombstone stream gaging stations (USGS Water Resources Data for Arizona, various years). It was assumed for this estimate that during the earliest period of record, before the basin was heavily pumped, that the water discharging from the aquifer to sustain baseflow of the river was equal to the water entering the aquifer from various recharge sources. The earliest period of baseflow records used was from 1935-1941. A full explanation is provided in Corell and others (1996).

The cross-border flux estimate was obtained from a flow net analysis (Putman and others, 1988). The recharge along Greenbush Draw was assumed by Corell and others (1996) to offset decades of pumping by the Arizona Water Company in that area. The Greenbush Draw area showed little or no groundwater decline until about 1990. Between 1990 and 2002 water levels had declined by 20 to 30 feet in some areas. Recharge in Greenbush Draw was assumed to be natural by Corell and others (1996), but recent discussions with Cochise County staff and Phelps Dodge staff revealed that the recharge probably came from discharge of mine water to evaporation ponds in the vicinity of Warren Ranch, near Naco, Arizona. This practice ended in 1987 (SAVCI Engineering Technology, 1998). The Greenbush Draw recharge estimate of 1,000 acre-feet was therefore removed from the prior estimate of 19,000 acre-feet used by Corell and others (1996). The revised estimate of 18,000 acre-feet was chosen for the water budget presented in Table 5. Recharge from flood flows of the San Pedro River is felt to be minimal in the Sierra Vista sub-area because the water levels in the floodplain alluvium are maintained at shallow levels, making little storage space available for long-term aquifer storage.

Recharge from various other sources such as recharge projects and septic tanks was estimated using information provided by the City of Sierra Vista, Fort Huachuca, and other water providers, as well as from water use estimates from Department staff. Full details are provided in ADWR's AMA Review Report (Arizona Department of Water Resources, 2005, in preparation). Recharge Facility Annual Reports filed with the Department by the City of Sierra Vista and a report by Ft. Huachuca (U.S. Army, 2002) show that about 1,500 acre-feet were recharged in 2002. Municipal and industrial incidental recharge was estimated at about 2,000 acre-feet per year. Total recharge to the groundwater system in the Sierra Vista sub-area is estimated at about 21,500 acre-feet per year.

<u>Benson Sub-Area</u>

Estimates of recharge in the Benson sub-area are based on fewer studies. The Department's HSR (1991) estimated mountain front recharge at about 11,800 acre-feet per year. Jahnke (1994) estimated mountain front recharge at about 10,700 acre-feet per year. Anderson and Freethey (1994) estimated mountain front recharge at 9,400 acre-feet per year. The budget presented in Table 5 uses 10,600 acre-feet per year, which is an average of the three estimates. Recharge from various other sources such as recharge projects and septic tanks was estimated using information provided by water providers, as well as from water use estimates from Department staff. Full details are provided in the AMA Review Report (Arizona Department of Water Resources, 2005, in preparation). Municipal and industrial incidental recharge was estimated at about 600 acre-feet per year.

Recharge from the San Pedro River constitutes a major source of recharge in the Benson sub-area but is poorly quantified due to lack of data. River recharge may occur during periods of baseflow and during flood events. A comparison of average monthly river flows at the USGS streamgage, "San Pedro River near Tombstone" (#09471550) and the USGS streamgage, "San Pedro River near Benson" (#09471800) at an area known as "The Narrows", was used to estimate transmission losses of river flows through the Benson sub-area (Arizona Department of Water Resources, Hydrology Division, unpublished analysis, May 2004; U.S. Geological Survey, 2004b). The only overlapping period for the two gages was 1967 to 1976, or 9 years of common record. This comparative study showed that average monthly inflows up to 25 cubic feet per second (cfs) almost always were completely lost to infiltration, evaporation, diversion, or riparian use within the Benson sub-area, and outflow at "The Narrows" was usually zero for these inflow rates. The transmission losses for monthly average flows under 25 cfs amounted to a total of about 48,000 acre-feet over 9 years, or an average of 5,300 acre-feet per year. As stated above, not all of the infiltrated water recharged the aquifer, since there were channel evaporative losses, diversions, and use by riparian vegetation.

Average monthly inflows above 25 cfs displayed a mixed pattern of losses or gains in flow within the Benson sub-area (Arizona Department of Water Resources, Hydrology Division, unpublished analysis, May 2004). Probable reasons for this were that the larger inflows represented larger, regional storm events, and considerable runoff was generated within both the Benson and Sierra Vista sub-areas. When precipitation was more intense within the Benson sub-area, the sub-area outflows exceeded the inflows. Between 1967 and 1976, there were 31 months when monthly average inflows exceeded 25 cfs. In 20 of the 31 months there were transmission losses within the Benson sub-area. In the other 11 months the sub-area outflows at "The Narrows" exceeded the inflows at the Tombstone gage. The transmission losses for the 20 months identified above amount to a total of 35,000 acre-feet over 9 years, or an average annual transmission loss of about 3,900 acre-feet. As stated above, not all of the infiltrated water recharged the aquifer, since there were channel evaporative losses, use by riparian vegetation, possible diversions, and perhaps bank storage discharge to the stream that later left the basin.

Average river infiltration for the period 1967-76 may therefore have been as high as 9,200 acre-feet from a combination of low flows (5,300 acre-feet) and flood flows (3,900 acre-feet), although this seems unlikely because of the riparian uses, evaporation and diversions noted above. A study of winter baseflows into the sub-area during 1997-2003 indicates that about 3,100 acre-feet of stream flow infiltrated into the streambed during that season. Because water use is minimal during the winter, this infiltrated baseflow recharged the groundwater system. Using an average between the high estimate of 9,200 acre-feet and the low value of 3,100 acre-feet gives an estimate of 6,150 acre-feet of river recharge. The estimate of 6,150 acre-feet of recharge is comprised of 3,100 acre-feet of winter baseflow out of the Sierra Vista sub-area and a balance of 3,050 acre-feet of recharge from higher flow events. This estimate should be regarded with caution because of the limited data available and because the time period of the data may not represent modern conditions.

An additional 440 acre-feet of underflow in the floodplain alluvium enters the Benson sub-area at the Tombstone gage. This quantity was determined using model results from Corell and others (1996). Total inflows to the Benson sub-area groundwater system are estimated at about 17,800 acre-feet per year.

Outflows

Following is a discussion of the water use by the sectors listed in Tables 2 and 3. Table 2 shows the groundwater and surface water supplies and demands of the various water use sectors in the USP basin, beginning in 1985. This information is based on the AMA Review Report for the basin (Arizona Department of Water Resources, 2005, in preparation). Table 3 shows the water demands for the Sierra Vista and Benson sub-areas.

Water used in the USP basin is mostly pumped from an aquifer. An estimated 27,820 acre-feet per year was pumped in the basin in 2002, mostly for municipal and military uses near Sierra Vista and Ft. Huachuca and for agricultural purposes near Benson and St. David (Table 2). Agricultural demand in Tables 2 and 3 is the consumptive use of the crops grown, not the amount of water diverted, pumped or applied to irrigated acres. Most fields in the USP basin are deficit irrigated, and recharge is minimal or non-existent. For this reason there is no irrigation recharge listed in Table 5. Consumptive use is the volume of water used by plants for growth and transpiration. The agricultural groundwater consumptive use volume can be compared to the municipal and industrial groundwater net use volume. Net groundwater use is the volume of groundwater pumped that is not returned to the aquifer through artificial or incidental recharge of effluent. Artificial recharge is the volume associated with the Fort Huachuca and Sierra Vista effluent recharge facilities. Incidental recharge is from septic tanks, golf course irrigation and effluent discharge.

Minor amounts of groundwater are used for stock and other industrial uses at this time. An additional 17,350 acre-feet per year of groundwater is used by riparian vegetation along the San Pedro and Babocomari Rivers (Cliff Dahm, personal commun., May, 2004; Scott and others, 2004, in preparation; Dahm and others, 2002; Chehbouni and others, 2000; Snyder and Williams, 2000). Additional riparian demand above that shown in Table 5 is supplied directly from precipitation and bank storage after flood events.

Agriculture

<u>Sierra Vista Sub-Area</u>
In 2003, ADWR staff visited potentially irrigated lands in the Sierra Vista sub-area to field verify their status. The Department estimated that 800 acres were being irrigated based upon a combination of field investigation, San Pedro HSR information, LANDSAT imagery and aerial photographs (Table 3). The Department was not able to verify that surface water was being diverted for agricultural use at that time, although a limited amount of surface water may be diverted at some locations.

In 1985, over 2,000 acres were estimated to be in agricultural production in the Sierra Vista sub-area (Arizona Department of Water Resources, 2005, in preparation). Establishment of the SPRNCA in 1988, housing developments, purchase of irrigated land for conservation purposes, and economic and other conditions have substantially reduced the number of agricultural acres in the sub-area. In addition, until 2002, about 300 acres were irrigated with effluent from the Sierra Vista Wastewater Treatment Plant. This acreage has been taken out of production, and the effluent is now diverted for groundwater recharge purposes.

Benson Sub-Area

Surface water is directly diverted for agricultural use in the Benson sub-area by the St. David Ditch and the Pomerene Canal. The St. David Ditch and Pomerene Canal were constructed in 1881 and 1912 respectively, to irrigate farmland near St. David, Benson, and Pomerene. There are few diversion records for the canals, but those that exist are presented in Table 4 of this report. These canals diverted an average of about 6,000 acre-feet per year between 1968 and 1972 (U.S. Geological Survey, 1968-72). At times, the water in the St. David Ditch and Pomerene Canal is heavily supplemented by water from wells (Putman and others, 1988). Putman and others (1988) noted that only 278 acres served by the St. David Ditch were irrigated entirely with surface water. The diversion structures for both canals were damaged by flood events and were not in use when the Department did a field survey of that area in May 2002.

Hourly pumpage and diversion records for the St. David Ditch supplied by the St. David Irrigation District to the Department indicated that about 3,500 acre-feet were pumped and diverted during 2001 for distribution by the ditch. No recent records were available for the Pomerene Canal. Total diversions by both canals were estimated at about 3,350 acre-feet for the period around 2002, using data from the ADWR HSR (1991) for the Pomerene Canal and recent data from the St. David Ditch Association. Data in the HSR show that 72%-76% of the diverted water to the Pomerene Canal and St. David Ditch served to satisfy consumptive crop use, thus about 2,300 acre-feet of surface water was assumed to satisfy crop consumptive use in the water budget presented in Table 3 for the Benson sub-area. The rest of the diverted water was returned to the river or lost to canal seepage. It should be noted that the precision of these estimates is, at best, to the nearest hundred acre-feet.

Table 2. USGS Stream Gaging Stations Located Directly Downstream of the Pomerene Canal and the St. David Ditch Diversion Works.

		Total Diversion in Acre-Feet [1]					
Station Number	**Station Name**	**1968**	**1969**	**1970**	**1971**	**1972**	**Average**
09471560	St. David Ditch near St. David, AZ	4,600	4,020	4,140	4,600	5,680[2]	4,608
09471590	Pomerene Canal near St. David, AZ	1,740	1,450	710	1,070	1,950	1,384

(Putman and others, 1988)

[1]Data from published USGS flow records (U.S. Geological Survey, 1968-72); gages began operating in June, 1967
[2]Release of diverted water back to river before usage had been measured as 5.46 cfs in January, 1972 and estimated as 0.1 cfs in March, 1972 (U.S. Geological Survey, 1968-72).

Farming use in the St. David-Benson-Pomerene area was estimated at about 7,300 acre-feet in 2002, based on a field survey of agricultural activity conducted by the Department in May 2002. This survey found about 2,150 acres being actively irrigated, mostly as pasture. The farming practice in the basin has been generally to deficit irrigate (Heindl, 1952; Arizona Department of Water Resources, HSR, 1991; Corell and others, 1996; Paul Kartchner, personal commun., February, 2002), and a consumptive use factor of 3.4 acre-feet per acre is regarded by ADWR as generally being the upper limit on agricultural use in the basin (Arizona Department of Water Resources, 1991). Water applied in excess of the consumptive use is recharged to the shallow aquifer underlying the fields along the river. Appendix D gives more detail on the Department's May, 2002 survey. Of the 7,300 acre-feet of agricultural consumptive use, 2,300 acre-feet was supplied by surface water diversions as discussed above, and 5,000 acre-feet was supplied by groundwater pumping.

Table 3. Groundwater and Surface Water Supplies and Anthropogenic Demands of the USP Basin.

	YEAR					
	1985	1990	2002	2010	2020	2030
AGRICULTURAL						
Irrigated acres	5,300	4,000	3,000	3,000	3,000	3,000
Demand (CU)[1]	**16,700**	**12,700**	**9,800**	**9,900**	**9,900**	**9,900**
Supply (CU)	16,700	12,700	9,800	9,900	9,900	9,900
Surface Water	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*	*2,300*
Effluent	1,100	1,300	0	0	0	0
Groundwater	*13,300*	*9,100*	*7,500*	*7,600*	*7,600*	*7,600*
MUNICIPAL						
Population	60,200	65,300	82,300	91,800	102,400	110,100
Demand	**13,600**	**14,300**	**18,900**	**22,300**	**25,200**	**27,200**
Water Provider	7,600	7,800	11,200	13,600	15,300	16,500
Fort Huachuca	3,300	3,100	1,900	1,900	1,900	1,900
Domestic Well	2,700	3,400	5,700	6,800	8,000	8,800
Supply	13,600	14,300	18,900	22,300	25,200	27,200
Surface Water	240	160	160	160	160	160
Effluent	340	340	800	1,100	1,400	1,600
Groundwater	13,000	13,800	17,900	21,000	23,600	25,400
(Less) Incidental Recharge[2]	*(1,600)*	*(1,700)*	*(2,600)*	*(2,800)*	*(3,100)*	*(3,300)*
(Less) Artificial Recharge[3]	*0*	*0*	*(1,500)*	*(3,900)*	*(4,500)*	*(5,100)*
Groundwater (Net use)[4]	*11,400*	*12,100*	*13,800*	*14,300*	*16,000*	*17,000*
INDUSTRIAL						
Demand	**1,700**	**1,900**	**2,100**	**2,100**	**2,600**	**2,600**
Supply	*1,700*	*1,900*	*2,100*	*2,100*	*2,600*	*2,600*
Surface Water	0	0	0	0	0	0
Effluent	0	0	0	570	570	570
Groundwater	1,700	1,900	2,100	1,500	2,000	2,000
(Less) Incidental Recharge	*(60)*	*(60)*	*(80)*	*(80)*	*(100)*	*(100)*
Groundwater (Net use)[4]	*1,600*	*1,800*	*2,000*	*1,400*	*1,900*	*1,900*
OTHER (Stock)						
Demand	**320**	**320**	**320**	**320**	**320**	**320**
Supply: Groundwater (Net use)[4]	*320*	*320*	*320*	*320*	*320*	*320*
TOTAL						
Total Water Use	**32,300**	**29,200**	**31,100**	**34,600**	**38,000**	**40,000**
Total Groundwater (Net use) [4]	*26,600*	*23,300*	*23,600*	*23,600*	*25,800*	*26,800*

NOTE: All units are in acre-feet unless otherwise noted. Numbers have been rounded to the nearest hundred or nearest ten. This may result in slight discrepancies in the totals.

1 Consumptive use is the volume of water used by plants for growth and transpiration.

2 Incidental recharge is recharge that occurs from septic tanks, turf watering and effluent discharge.

3 Artificial recharge is recharge of effluent in recharge basins or channels.

4 Net use is the volume of groundwater pumped and not returned to the aquifer through artificial or incidental recharge.

Table 4. Groundwater and Surface Water Supplies and Anthropogenic Demands, Sierra Vista and Benson Sub-areas.

SECTOR	1985		1990		2002		2010		2020		2030	
	SV	BEN	SV	BEN	SV	BEN	SV	BEN	SV	BEN	SV	BEN
AGRICULTURAL												
Irrigated acres	2,000	3,200	1,400	2,600	800	2,200	800	2,200	800	2,200	800	2,200
Demand (CU[1])	**5,900**	**10,800**	**3,900**	**8,800**	**2,500**	**7,300**	**2,500**	**7,400**	**2,500**	**7,400**	**2,500**	**7,400**
Supply (CU)	*5,900*	*10,800*	*3,900*	*8,800*	*2,500*	*7,300*	*2,500*	*7,400*	*2,500*	*7,400*	*2,500*	*7,400*
Surface Water	0	2,300	0	2,300	0	2,300	0	2,300	0	2,300	0	2,300
Effluent	870	240	1,100	180	0	0	0	0	0	0	0	0
Groundwater	*5,000*	*8,300*	*2,800*	*6,300*	*2,500*	*5,000*	*2,500*	*5,100*	*2,500*	*5,100*	*2,500*	*5,100*
MUNICIPAL												
Population	52,200	8,000	56,600	8,700	70,100	12,200	76,500	15,300	85,100	17,300	91,700	18,400
Demand	**11,600**	**2,000**	**12,100**	**2,200**	**15,100**	**3,700**	**16,600**	**5,700**	**18,600**	**6,600**	**20,000**	**7,000**
Water Provider	6,600	1,000	6,700	1,000	9,300	2,000	10,100	3,500	11,300	4,000	12,100	4,400
Fort Huachuca	3,300		3,100		1,900		1,900		1,900		1,900	
Domestic Well	1,700	1,000	2,300	1,200	3,900	1,800	4,500	2,300	5,400	2,600	6,000	2,700
Supply	*11,600*	*2,000*	*12,100*	*2,200*	*15,100*	*3,700*	*16,600*	*5,700*	*18,600*	*6,600*	*20,000*	*7,100*
Surface Water	240	0	160	0	160	0	160	0	160	0	160	0
Effluent	340	0	340	0	420	380	370	700	370	1,000	370	1,200
Groundwater	11,000	2,000	11,600	2,200	14,600	3,300	16,100	5,000	18,100	5,600	19,500	5,900
(Less) Incidental Recharge[2]	*(1,300)*	*(270)*	*(1,400)*	*(310)*	*(2,000)*	*(590)*	*(2,100)*	*(680)*	*(2,300)*	*(790)*	*(2,500)*	*(840)*
(Less) Artificial Recharge[3]	*0*	*0*	*0*	*0*	*(1,500)*	*0*	*(3,900)*	*0*	*(4,500)*	*0*	*(5,100)*	*0*
Groundwater (Net use)[4]	*9,700*	*1,700*	*10,200*	*1,900*	*11,100*	*2,700*	*10,100*	*4,300*	*11,300*	*4,800*	*11,900*	*5,100*
INDUSTRIAL												
Demand	**1,200**	**500**	**1,200**	**710**	**1,300**	**830**	**1,300**	**830**	**1,800**	**830**	**1,800**	**830**
Supply	*1,200*	*500*	*1,200*	*710*	*1,300*	*830*	*1,300*	*830*	*1,800*	*830*	*1,800*	*830*
Surface Water	0	0	0	0	0	0	0	0	0	0	0	0
Effluent	0	0	0	0	0	0	570	0	570	0	570	0
Groundwater	1,200	500	1,200	710	1,300	830	700	830	1,200	830	1,200	830
(Less) Incidental Recharge	*(50)*	*(10)*	*(50)*	*(10)*	*(50)*	*(30)*	*(50)*	*(30)*	*(80)*	*(30)*	*(80)*	*(30)*
Groundwater (Net use)[4]	*1,200*	*490*	*1,200*	*700*	*1,300*	*800*	*650*	*800*	*1,100*	*800*	*1,100*	*800*
OTHER (Stock)												
Demand	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**	**160**
Supply: Groundwater (Net use)[4]	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*	*160*
TOTAL												
Total Water Use	**18,800**	**13,500**	**17,400**	**11,800**	**19,100**	**12,000**	**20,500**	**14,100**	**23,000**	**15,000**	**24,500**	**15,500**
Total Groundwater (Net use)[4]	*15,900*	*10,700*	*14,200*	*9,100*	*15,100*	*8,600*	*13,300*	*10,400*	*15,000*	*10,900*	*15,700*	*11,200*

NOTE: All units are in acre-feet unless otherwise noted. Numbers have been rounded to the nearest hundred or nearest ten. This may result in slight discrepancies in the totals.

1 Consumptive use is the volume of water used by plants for growth and transpiration.

2 Incidental recharge is recharge that occurs from septic tanks, turf watering and effluent discharge.

3 Artificial recharge is recharge of effluent in recharge basins or channels.

4 Net use is the volume of groundwater pumped and not returned to the aquifer through artificial or incidental recharge.

The amount of groundwater pumped from the Allen Flat sub-basin is used primarily for stock and domestic supplies. Burtell (1989) includes a detailed list of water use for each well inventoried. Additionally, a recent review of registered wells and associated water uses indicate the following: stock use – 60%, stock and domestic use – 18%, domestic use – 12%, and mineral exploration – 10% (Arizona Department of Water Resources, Well Registration Files, 2002).

Municipal

Municipal demand includes water served by public and private water systems, water use at Fort Huachuca and exempt well demand. Included in this demand is residential, non-residential, golf course and industrial use served by a water system. Only three water systems are publicly owned: City of Benson, City of Tombstone and Huachuca City. Municipal demand is linked to population and population growth estimates were used to generate future municipal water demands. This report uses data from the 2002 estimates from the Arizona Department of Economic Security (DES), and from the 2000 United States Census which were the most recent estimates available at the time of review.

Municipal water use information came from several sources. A primary source was the Arizona Corporation Commission (ACC), which regulates private water company rates and requires annual reporting of the volume of water pumped and the volume of water sold to customers. In cases where pumpage is not reported, it is necessary to adjust delivery information to include system water losses. An assumption of 10% losses was used for providers that would be classified as large if within an AMA (pumping more than 250 acre-feet per year) and 15% for smaller providers (Arizona Department of Water Resources, 1999). Other information on municipal water use came from direct communication with water providers and from estimates of water use for domestic wells.

Exempt well demand is not metered or reported. Exempt well demand was estimated based on large lot parcel use in the Tucson AMA for which a long history of metered water use is available, with an additional demand associated with irrigated lands of less than two acres in size based on information in the San Pedro HSR (Arizona Department of Water Resources, 1991). Because proportionately more small irrigated lands exist in the Benson sub-area, the per person use estimate differs between sub-areas. Full details on the exempt well methodology are provided in the AMA Review Report (Arizona Department of Water Resources, 2005, in preparation).

Almost all the water supply for municipal use is groundwater. Effluent is served by municipal water providers for turf irrigation in both sub-areas and a small volume of surface water is used in the Sierra Vista sub-area.

<u>Sierra Vista Sub-Area</u>
Approximately 80% of the basin municipal demand occurs in the Sierra Vista sub-area. In 2002, water system demand was about 9,300 acre-feet, Fort Huachuca demand was about 1,900 acre-feet and exempt well use about 3,900 acre-feet (U.S. Army, 2002). Exempt well demand was estimated at 0.35 acre-feet/person per year based on the methodology explained above. No adjustments to the DES projections were made to project population or demand for the sub-area.

Ninety-six percent of the municipal water supply in the Sierra Vista sub-area is groundwater. After use, approximately 3,500 acre-feet of water is returned to the aquifer as incidental or artificial recharge. In 2002, about 420 acre-feet of effluent was directly used for turf irrigation at Fort Huachuca.

Surface water is diverted for use in Tombstone by the Tombstone pipeline. The pipeline was constructed in 1887 by the Huachuca Water Company to bring water to Tombstone as a municipal supply (Bryan and others, 1934). It is still in operation and consists of an 8-inch pipeline running eastward 25 miles across the basin from Miller Canyon in the Huachuca Mountains to Tombstone. The Tombstone groundwater and surface water supplies are commingled and not separately measured at this time. Surface water use is estimated at 156 acre-feet per year as reported in the 1988 Putman and others report.

Benson Sub-Area

In 2002, total water system demand was about 2,000 acre-feet. Effluent supplied about 400 acre-feet of this demand. Exempt well demand was about 1,800 acre-feet. As mentioned previously, there is proportionately more irrigated land less than two acres in size in the Benson sub-area compared to the Sierra Vista sub-area (Arizona Department of Water Resources, 1991). Therefore, the exempt well demand in the Benson sub-area was estimated to be 0.59 acre-feet/person per year. Some adjustments were made to the DES projections for the Benson sub-area to include approved developments at Whetstone Ranch and at Bachmann Springs (City of Benson Designation of Adequate Water Supply application dated October, 2000; Mark Holt, City Manager, Benson, personal commun., September, 2002; and Mark Apel, Cochise County Planning Department, personal commun., August, 2002). These developments will be served with a combination of effluent and groundwater from municipal wells.

Approximately 85% of the municipal water supply in the sub-area is groundwater. About 600 acre-feet of effluent are returned to the aquifer as incidental recharge. In 2002, about 380 acre-feet of effluent was directly used for turf irrigation at the San Pedro Golf Course.

Industrial

For the purposes of this report, industrial water demand is an industrial type use served by its own well, not by a water company. Industrial water demand in the basin consists of five sand and gravel facilities, one dairy, an ammonium nitrate manufacturing plant, and three golf courses. All the sand and gravel facilities and two of the industrial golf courses are located in the Sierra Vista sub-area. In 2002, industrial demand in the Sierra Vista sub-area was 1,300 acre-feet. One industrial golf course, the dairy and the ammonium nitrate plant (Apache Nitrogen), are located in the Benson sub-area. These facilities used approximately 800 acre-feet of groundwater in 2002. ADWR identified golf courses and other turf-related facilities (ten or more acres of water-intensive landscaping) through reports, interviews and satellite imagery. Water use was estimated for most of these facilities, although data was reported to ADWR for Apache Nitrogen and was available for Turquoise Valley Golf Course (U.S. Environmental Protection Agency, 2003). Golf course use was estimated at about 1,550 acre-feet, sand and gravel use at 200 acre-feet and the dairy at about 40 acre-feet. Approximately 80 acre-feet of water used for industrial turf irrigation returns to the aquifer as incidental recharge. Approximately 300 acre-feet are used at the Apache Nitrogen facility. All current water supplies are groundwater.

Stock

A small volume of groundwater, about 300 acre-feet, was assumed to be used for stockwatering purposes. This information was estimated from a Cochise County total livestock number prorated on a per acre basis for the basin and split evenly between the sub-areas. A use of 12 gallons per head per day was assumed.

Riparian

Sierra Vista Sub-Area

The riparian vegetative community along the San Pedro River uses a large amount of water in the basin. This demand is therefore a critical component of the water budget, yet is among the hardest to estimate. A portion of the water use by the riparian vegetation comes from an aquifer system, and a portion comes from precipitation, post-flood bank storage, and efficient utilization of percolation into the vadose zone (Corell and others, 1996; Chehbouni and others, 2000; Snyder and Williams, 2000).

Previous estimates of total evapotranspiration have ranged from about 14,000 acre-feet to 17,000 acre-feet for the portion of the basin south of Fairbank (Freethey, 1982; Putman and others, 1988; Corell and others, 1996). Some of the total demand is supplied by groundwater, some by surface water, and some by precipitation. A study by the Agricultural Research Service of the U.S. Department of Agriculture (Scott and others, 2004, in preparation) estimates that riparian groundwater use in the Sierra Vista sub-area ranged from 7,330 to 8,970 acre-feet per year for 2003, or an average of 8,150 acre-feet per year. The model-calibrated value of 7,700 acre-feet per year of riparian use from Corell and others (1996) was used in Table 5 for the Sierra Vista sub-area because this estimate was felt to represent a longer period of time than the three years estimated in the study by Scott and others (2004, in preparation). The 7,700 acre-feet of groundwater demand was about half of the Corell and others (1996) estimate of total riparian demand.

Benson Sub-Area

For the Benson sub-area, total surface water and groundwater use by riparian vegetation had been previously estimated for several studies. Putman and others (1988) estimated riparian use at about 16,200 acre-feet per year. Following Corell and others (1996), half this demand was assumed to be supplied by groundwater and half by surface water or precipitation. Thus this estimate was adjusted to include 8,100 acre-feet of groundwater demand. Jahnke (1994) estimated total evapotranspiration in the "Benson basin" at about 21,900 acre-feet per year. Jahnke's model-calibrated value for evapotranspiration was 16,200 acre-feet per year. Anderson and Freethey (1994) used a conceptual range of 5,100 acre-feet to 16,700 acre-feet, and simulated 7,100 acre-feet in their model. The Anderson and Freethey model simulation ended in 1977, and more recent estimates were used for the water budget presented in Table 5.

Several recently completed studies were used for the estimate of riparian groundwater use presented in Table 5. Data from Scott and others (2004, in preparation) was combined with aerial photo analysis by the U.S. Fish and Wildlife Service (2002) to derive estimates of riparian water use for the Benson sub-area. Scott and others estimated the groundwater use by mesquite, cottonwood, willow and other vegetative communities for the San Pedro Riparian National Conservation Area (SPRNCA). Scott and others (2004, in preparation) estimated that about 3,500 acre-feet of groundwater was used by the riparian community within the portion of SPRNCA that lies in the Benson sub-area. For the portion of the Benson sub-area outside SPRNCA, the community type use rates from Scott and others (2004, in preparation) were combined with acreage estimates for various plant community types from the U.S. Fish and Wildlife Service (2002). Percent canopy cover was estimated from aerial photography (Arizona Regional Image Archive, 2004) for the mesquite vegetative categories that comprised the majority of the riparian acreage.

Salt cedar (*Tamarix sp.*) is found in the Benson sub-area, but not in the Sierra Vista sub-area, and it was necessary to make an estimate for salt cedar use. The consumptive use estimate for salt cedar was taken from work by Dahm and others (2002) along a perennial reach of the Rio Grande in New Mexico. In a setting where depth to water was greater than 4 meters, Dahm reported that the evapotranspiration rate for a dense stand of salt cedar was greatly reduced to half the rate found in a similar stand where depth to water was two to three meters below land surface. A reduction in demand of 50% was therefore applied to salt cedar along the San Pedro River because of the greater depth to groundwater and intermittent nature of the stream in the Benson sub-area. This reduction was based on information provided during a telephone conversation with Dr. Dahm (May 17, 2004).

The methodology used in estimating groundwater use from the riparian inventory for the Benson sub-area outside of SPRNCA is discussed in Appendix E. An estimate of 6,150 acre-feet of riparian demand was obtained for the Benson sub-area outside of SPRNCA using the data sources and methodology described above, and Scott and others (2004, in preparation) provided an estimate of 3,500 acre-feet for riparian demand for the Benson sub-area within SPRNCA, for a total estimated riparian groundwater demand of 9,650 acre-feet. This demand is shown in Table 5.

Underflow

A very small amount of groundwater flows out of the Benson sub-area at "The Narrows" as underflow. Heindle (1952) estimated 100 acre-feet per year through "The Narrows". Geologic mapping by Drewes (1974) shows "The Narrows" as a shallow gap in the Johnny Lyon granodiorite about 200 to 300 feet wide. Freethey and Anderson (1994) estimated an outflow of about 1,100 acre-feet per year based on regional modeling. Their estimate came from a constant head model boundary however, and underlying data assumptions to check the validity of the estimate are not available. A geophysics thesis showing depth to bedrock in the area was also examined (Halverson, 1984). The thesis data are quite extensive to the north and south of "The Narrows", but do not extend into the bedrock area to either side of "The Narrows", shedding no definitive light on the question of underflow. Halverson postulates depths to bedrock of over 1,000 feet to the north and south of "The Narrows", however her contours indicate considerable shallowing as "The Narrows" and adjacent mountain fronts are approached. Drewes (1974) has mapped outcrops of granodiorite in the area of "The Narrows" that indicate alluvial material in the area may be quite shallow. Aquifer test data supplied by The Nature Conservancy at the Three Links Farm (written correspondence from James Lombard to David Harris, The Nature Conservancy, dated August 6, 2003) was also used to estimate underflow through the floodplain alluvium of "The Narrows". This test provided an estimated transmissivity value of 43,000 ft^2/day. This transmissivity value was used at "The Narrows" to estimate underflow using a flow net analysis. A channel width of 300 feet was used together with a water table slope of 25 feet per mile (equal to the slope of the riverbed surface). The resulting underflow estimate shown in the present report is about 200 acre-feet per year leaving the Upper San Pedro basin at "The Narrows". This value is used in Table 5 of the present report.

Intra-basin Groundwater Transfers

Another groundwater outflow component is the baseflow of the San Pedro River, as measured at the USGS streamgage, "San Pedro River near Tombstone" (#09471550). This outflow is actually a transfer of water from one part of the basin to another, and as such is reflected in the sub-area budgets, but not in the basin-wide budget in Table 5. Flow data from 1997 to 2004 show an average non-flood related stream flow leaving the Sierra Vista sub-area of about 3,250 acre-feet per year. Flow diminished rapidly after the winter months, and zero baseflows are generally recorded during late spring, summer, and fall. Winter baseflows (November-March) averaged about 3,100 acre-feet per year. An additional 150 acre-feet of baseflow on average left the Sierra Vista sub-area during late spring and early fall. This volume was felt to be used by riparian vegetation before it recharged the groundwater system.

Recharge from baseflow transferring from the Sierra Vista sub-area to the Benson sub-area during the winter (November- March) period of 1996-2003 was estimated at 3,100 acre-feet. This lesser volume was felt to recharge the Benson sub-area groundwater system because the riparian system that might have used this water was dormant. The recharge from baseflow is reflected in the Benson sub-area budget but not in the basin-wide budget for reasons explained above. An additional transfer of about 440 acre-feet per year at the gage site occurs as underflow in the floodplain alluvium (Corell and others, 1996).

Discussion of Groundwater Budget

Identifying major inflows to and outflows from the groundwater system of the USP basin has allowed construction of the groundwater budgets shown in Table 5. Table 5 presents a groundwater budget for the entire Upper San Pedro basin as well as for the Sierra Vista sub-area and the Benson sub-area. Mountain front recharge is the major source of recharge to the aquifer in the USP basin. Infiltration of river flows is another major source of recharge. Evapotranspiration by riparian vegetation is a major groundwater use in the basin as a whole. These components are among the more difficult water budget components to measure.

The groundwater budget shown in Table 5 for the Sierra Vista sub-area is based on a number of scientific studies over a number of years, and is relatively well understood. Estimates of both mountain front recharge and riparian use, while difficult to directly measure, are more firm in the Sierra Vista sub-area, which has been more thoroughly studied and where the hydrologic conditions lend themselves to better data collection. In the Benson sub-area, fewer studies, less data and more complex hydrologic conditions make the estimates presented less certain than in the Sierra Vista sub-area.

The groundwater budget for the Benson sub-area was constructed with the assumption of little or no groundwater outflow northward out of the sub-area, which in turn implies that consumption of groundwater is greater than recharge for the area. The USGS streamgage, "San Pedro River near Benson", also referred to as "The Narrows" was operational from 1967 to 1976, and the gage data showed little or no baseflow leaving the groundwater basin most days of most years. This indicates that the groundwater budget outflows are greater than the inflows for the Benson sub-area. The water budget in Table 5 reflects this.

The change in groundwater storage estimate is the difference between total inflow and total outflow for the basin or sub-area. In the Sierra Vista sub-area the change in groundwater storage is about –8,350 acre-feet per year. The water budget for this sub-area includes a transfer of 3,250 acre-feet of baseflow to the Benson sub-area. The Benson sub-area shows a change in groundwater storage of –1,320 acre-feet.

Both the estimate of total inflow (35,750 acre-feet per year) and total outflow (45,270 acre-feet per year) for the Upper San Pedro basin do not include the exchange of baseflow and underflow between the Sierra Vista and Benson sub-areas. For this reason one cannot simply add up the change in storage for both sub-areas and find the total basin change in storage. The annual change in storage for the Upper San Pedro basin is about –9,520 acre-feet per year. Total groundwater in storage in the Upper San Pedro basin is estimated at about 20 to 26 million acre-feet.

Table 5. Average Annual Groundwater Budget for the USP Basin, ca 2002.

Inflows to Groundwater System	Sierra Vista Sub-area	Remarks	Benson Sub-area	Remarks
Mountain Front, Ephemeral Channel, Cross-border Flux	18,000	From Corell and others (1996). Adjusted to eliminate Greenbush Draw recharge.	10,600	Average of estimates: ADWR HSR (1991) Jahnke (1994) Anderson and Freethey (1994)
Artificial Recharge	1,500	Table 3	0	Table 3
Incidental Recharge	2,000	Table 3	600	Table 3
Baseflow and Underflow into Sub-area*	---	Included with mountain front recharge estimate	440 3,100 3,050	Model underflow from Corell and others (1996) Baseflow data at USGS Tombstone and "The Narrows"gages** Flood recharge estimated from USGS gage data**
Total Inflow	**21,500**		**17,790**	

Outflows from Groundwater System	Sierra Vista Sub-area	Remarks	Benson Sub-area	Remarks
Agricultural Demand	2,500	Table 3	5,000	Table 3
Municipal Demand	14,500	Table 3 - excludes effluent	3,300	Table 3 – excludes effluent
Industrial Demand	1,300	Table 3	800	Table 3
Stock Demand	160	Table 3	160	Table 3
Riparian Use	7,700	50% of total riparian demand, from Corell and others (1996)	9,650	From ARIA (2004) and USFWS (2002); use rates from Scott and others (2004) and Dahm and others (2002)
Underflow from Sub-area*	440	At Tombstone gage site. From Corell and others (1996)	200	Underflow through "The Narrows" from flow net analysis
Baseflow Out*	3,250	At Tombstone gage site for 1997-2003. From USGS gage data***	NA	From USGS gage records at Benson ("The Narrows")
Total GW Demand	**29,850**		**19,110**	
Change in Storage	**-8,350**		**-1,320**	

NOTE: All values are in acre-feet per year. Estimates are shown to the nearest 10 acre-feet for calculation purposes, but should not be considered this accurate.

BASIN TOTALS

* Estimates of total inflow and total outflow for the entire basin do not include transfer of baseflow and underflow between the Sierra Vista and Benson sub-areas.

** Includes 3,100 af of recharge from baseflow from the Sierra Vista sub-area and 3,050 af of recharge from flood events in the Benson sub-area. The 3,100 af does not appear in the basin-wide water budget as recharge because it represents a transfer of water within the basin groundwater system; not an addition of water to the aquifer.

*** Average baseflow at the Tombstone gage for 1997-2003. Based on flows for non-flood influenced months between September and May of this period.

Total Inflow	+35,750	
Total Outflow	-45,270	
CHANGE IN STORAGE	**-9,500**	***(rounded)***

Land Subsidence

The second factor that the Department must consider to determine whether to designate an AMA is whether "land subsidence or fissuring is endangering property or potential groundwater storage capacity" (A.R.S. § 45-412.A.2). There are limited data available to the Department for this determination within the USP basin.

Land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials (U. S. Geological Survey, 1999). This subsidence may be caused by such factors as aquifer-system compaction, drainage of organic soils, underground mining (e.g. at Tombstone), hydrocompaction, natural compaction, sinkholes, and thawing permafrost (National Research Council, 1991). The type of subsidence considered in this document is aquifer-system compaction caused by groundwater pumping.

When water is extracted from the ground at rates greater than it is recharged, there is a lowering of the water table (unconfined aquifer system) or a lowering of the potentiometric surface (confined or artesian aquifer system). When the stress applied to these systems exceeds the pre-consolidation stress threshold, the fine-grained constituents can be rearranged and become packed more closely together. This subsurface compaction of material causes the land surface to subside. If the aquifer system is primarily coarse-grained material it is possible that an increase in stress can be supported by grain-to-grain contact, without rearrangement and without land subsidence.

The two primary factors controlling whether subsidence will occur, and if so the amount of the subsidence, are the magnitude of the water table change or lowering of the potentiometric surface, and the percentage of fine-grained material (clays/silt) within the aquifer system. Within areas of central and southern Arizona there have been declines in the water table of several hundred feet or more. In some of these areas the aquifer system is composed of thousands of feet of unconsolidated gravel, sand, silt, and clay. Land subsidence has occurred in basins in which water levels have declined several hundred feet and which also contain basin-fill deposits having a relatively high silt and clay content.

Sierra Vista Sub-Basin

The potential for land subsidence exists within the Sierra Vista sub-basin if the conditions discussed above are met. Currently a land subsidence monitoring network is not in place within the Sierra Vista sub-basin; however, the USGS has established a network of gravity/GPS stations within certain areas of the sub-basin that could be used as part of a subsidence monitoring network. At this time there are no known documented occurrences of land subsidence caused by aquifer system compaction (personal commun. with Ray Harris, Arizona Geological Survey, Tucson, AZ, and Don Pool, U.S. Geological Survey Hydrologic Investigations and Research Program, Tucson, AZ, 2002). Subsidence does not seem likely for most portions of the Sierra Vista sub-basin given the comparatively small water-level changes from pre-development conditions. At this time, neither land subsidence nor fissuring is endangering property or potential groundwater storage.

Allen Flat Sub-Basin

Specific land subsidence information is not available for the Allen Flat sub-basin. A crucial factor in land subsidence depends on significant groundwater withdrawals. There is little groundwater use in the Allen Flat sub-basin and subsidence from aquifer system compaction caused by groundwater pumping would not be expected to occur in this area.

Water Quality

The last factor that the Department must consider to determine the need for an AMA, is whether "use of groundwater is resulting in actual or threatened water quality degradation" (A.R.S. § 45-412.A.3). In order to make this determination the Department evaluated water quality data for the Sierra Vista sub-basin and the Allen Flat sub-basin.

Sierra Vista Sub-Basin

Groundwater quality in the Sierra Vista sub-basin has been evaluated and documented in several reports by a number of investigators (Bryan and others, 1934; Heindl, 1952; Brown and others, 1966; Roeske and Werrell, 1973; Konieczki, 1980; Thompson and others, 1984; Barnes, 1997; Coes and others, 1999; Pool and Coes, 1999; Arizona Department of Environmental Quality, 2000; and Cordy and others, 2000). The reports give a general description of the geochemistry of groundwater in the sub-basin.

Water in the regional (basin fill) aquifer is predominantly a calcium-bicarbonate type with total dissolved solids (TDS) in the range of 200 to 400 milligrams per liter (mg/L) (Thompson and others, 1984; Konieczki, 1980). Along the San Pedro River near Palominas, between Hereford and Lewis Springs, and between St. David and "The Narrows," groundwater evolves to a sodium bicarbonate and sodium-sulfate type water, with TDS rising to greater than 1,000 mg/L in some cases. These areas of elevated TDS generally correspond to the confined areas of the regional aquifer.

Heindl (1952) found that shallow groundwater was higher in TDS than groundwater at depths greater than 600 feet and was calcium-sulfate or sodium sulfate type water. Previous investigators noted elevated fluoride concentrations in the St. David-Benson area (Bryan and others, 1934; Thompson and others, 1984) and elevated sulfate concentrations in the St. David-Pomerene area (Roeske and Werrell, 1973; Thompson and others, 1984). Later investigations by the USGS and the Arizona Department of Environmental Quality (ADEQ) report findings similar to the earlier studies (Coes and other, 1999; Pool and Coes, 1999; and Cordy and others, 2000).

The USGS and ADEQ conducted a cooperative water-quality assessment of the Sierra Vista sub-basin of the USP basin (Coes and others, 1999). Thirty-nine groundwater samples were collected in 1996 - 1997 and analyzed for general mineral constituents, physical and chemical characteristics, nutrients, and trace constituents. The results were compared to U.S. Environmental Protection Agency primary and secondary maximum contaminant levels (MCLs) for drinking water. Primary MCLs are enforceable, health-based standards that specify the maximum concentration of a constituent that is allowed in a public water system. Secondary MCLs are unenforceable standards that are generally related to aesthetics. The effects of location, well depth, aquifer type, geology, and land use on the results were evaluated. The data set was compared to a historical data set from 1950 – 1965.

Coes and others (1999) concluded that groundwater in the basin is suitable for all water uses. Only one sample (4.5 mg/L fluoride) exceeded the primary MCL of 4 milligrams per liter (mg/L) fluoride. Several samples exceeded secondary MCLs for fluoride, iron, manganese, sulfate, TDS, and pH. The report noted that the concentrations of chemical constituents that exceeded MCLs and variations in quality could be attributed to natural geochemical reactions and/or associated with corroding well casing.

Arsenic was detected in about 35% of the groundwater samples collected by Coes and others (1999); all of these samples met the current 50 part per billion (ppb) standard. The U.S. Environmental Protection Agency now requires public water systems to lower the allowable arsenic content in drinking water from 50 ppb to 10 ppb by January 23, 2006 (Arizona Department of Environmental Quality, 2003a). Four of the samples collected by Coes and others (1999), had arsenic concentrations exceeding the new standard of 10 ppb, with arsenic levels ranging from 11 to 33 ppb. These samples were collected about three miles northwest of Tombstone (two samples), about ten miles northeast of St. David near the Dragoon Mountains, and about two to three miles southwest of "The Narrows" (Coes and others, 1999).

In addition, between 1996 and 2004, six Benson City wells, two Pomerene Domestic Water User Association wells, three Tombstone City wells, two Cochise Junior College wells and three Apache Nitrogen Product wells have been identified as having arsenic levels above the new standard of 10 ppb (Arizona Department of Environmental Quality, 2004). With the exception of the Tombstone City wells, all of the arsenic exceedences are in the Benson sub-area.

Consistent with previous investigations, Coes and others (1999) found that groundwater in the Sierra Vista sub-basin is a calcium-bicarbonate type. TDS ranged from 131 mg/L to 1,250 mg/L. Statistically significant variations in groundwater quality versus well depth, well location, and aquifer type were identified. Sodium concentrations are generally higher in the basin-fill aquifer in the St. David area than in the southern half of the basin. Temperature, pH, and calcium concentrations varied with well depth. Temperature and pH generally increases with depth. Calcium concentrations generally decrease with depth. No statistically significant differences were identified between groundwater quality and geology, land use, or with time (Coes and others, 1999).

A hydrogeologic investigation of the Sierra Vista sub-basin (Pool and Coes, 1999) was conducted by the USGS concurrently with the groundwater quality assessment (Coes and others, 1999). Groundwater samples from the water quality assessment and additional samples collected were used to define groundwater flow paths and quantify the sources of base flow to the San Pedro River above the Charleston gage. Additional data analysis included stable isotopes of hydrogen and oxygen, and tritium concentrations.

Specific conductance was measured in groundwater and found to be quite variable. Specific conductance is a measure correlated to TDS. Specific conductance was generally higher in the floodplain alluvium than other water sources, averaging 558 microsiemens per centimeter (µS/cm) and 550 µS/cm, respectively. The cause of the elevated specific conductance (or TDS) is poorly understood, but can be attributed to evaporative concentration, infiltration of high TDS surface flow, and dissolution of gypsum in the regional aquifer. An extensive record of specific conductance at the Charleston stream gage indicates that runoff is not a likely source of the elevated TDS (Pool and Coes, 1999).

Contamination from mining, municipal, industrial, military, and commercial activities throughout the basin could potentially threaten groundwater resources, however, the threats are localized. These include releases from the copper mines in Cananea, Mexico, and Bisbee, Arizona; cyanide leaching solution spills into Walnut Gulch; sanitary sewer overflows discharging to tributaries of Greenbush Draw from Naco, Sonora; contamination from septic systems; and industrial contamination from past activities at Apache Powder and Ft. Huachuca.

Tailings ponds associated with Phelps-Dodge Corporation's mining operations at Bisbee are located on the headwater of a tributary to the San Pedro River. Leaks and spills from these operations can potentially contaminate groundwater. However, Phelps-Dodge has applied for an Aquifer Protection Permit from the ADEQ, an agency responsible for water quality regulation and enforcement. The application is currently under review and is expected to be issued in mid-2005 (E. Wilson, Arizona Department of Environmental Quality, personal commun., February, 2005). Mine infrastructure improvements in Cananea have significantly reduced, if not eliminated, releases from Mexico since the late 1980s. This threat is monitored by ADEQ with a six station network of monitoring sites (H. Huth, Arizona Department of Environmental Quality, personal commun., February, 2005). Several abandoned mill sites, remnants of historic mining in Tombstone, exist along the San Pedro River. There is no known documentation of water quality associated with these sites, yet the potential for adverse impacts exists (Jim Leenhouts, U.S. Geological Survey, written commun., Feb. 10, 2004).

The City of Naco, Sonora has received assistance from the North American Development Bank to upgrade its sewage lagoons, which were completed in 2003. The treatment facility is currently operating at the plant capacity of 250,000 gallons per day (C. Tinney, Arizona Department of Environmental Quality, personal commun., February, 2005). Untreated releases have entered the United States into tributaries of Greenbush Draw, but have been significantly curtailed with the plant modifications.

The City of Bisbee is operating under an ADEQ Consent Order to address inflow/infiltration and effluent quality issues with the wastewater collection and treatment system (www.epa.gov/region09/border/bisbee/index.html). In addition, the EPA has issued a Finding of Violation and Notice for Compliance to address discharge permit violations. Some parts of the collection system are old and in poor condition, resulting in sewer overflows. Exceedences of treatment plant capacity have resulted in releases of raw or partially treated sewage. The City of Bisbee was awarded a Border Environment Infrastructure Fund grant in September 2003, which along with other financial sources will provide funds to repair the collection system and consolidate wastewater treatment, now done at three separate wastewater treatment plants (WWTP), at the San Jose WWTP. Plans are for the wastewater to be treated to sufficient quality to irrigate the Turquoise Valley Golf Course in Naco, and when irrigation needs are low, to put excess wastewater into Greenbush Draw.

A number of communities such as Palominas, Hereford, St. David, and Pomerene do not have centralized wastewater treatment systems and rely on septic tanks and leach fields for waste disposal. These septic systems and leach fields pose a potential localized threat to water quality (C. Tinney, Arizona Department of Environmental Quality, personal commun., February, 2005).

The Apache Powder Superfund Site is located approximately 2.5 miles southwest of St. David and is bounded by the San Pedro River on the east. Apache Nitrogen Products, Inc. (ANP), formerly known as Apache Powder Company, owns and operates a fertilizer and nitric acid manufacturing plant at the site. Soil, groundwater and surface water contamination has occurred at the site due to past manufacturing and disposal practices at Apache Powder Company. Sampling has identified a nitrate contaminated plume at the site affecting both groundwater and a short reach of the San Pedro River. Additional contaminants of concern at the site include arsenic, fluoride, perchlorates and metals (Arizona Department of Environmental Quality, 2003b). Cleanup efforts to date include removal of waste barrels and contaminated soils, and construction of a treatment wetland. A future cleanup schedule has been developed by ANP and remedial activities are being coordinated with the EPA and ADEQ.

Several environmental cleanups involving contaminated soils have been performed at Fort Huachuca, but no groundwater problems have been identified. These sites are part of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) cleanup funded by the Department of Defense Installation Restoration Program. Groundwater monitoring wells have been installed at the South Range Landfill and the East Range Mine Shaft and are periodically sampled to monitor for contamination. No groundwater contamination has been detected at either location (Arizona Department of Environmental Quality website http://www.azdeq.gov/environ.waste/sps/statesites.htm|#fthcha; Brian Stonebrink, Arizona Department of Environmental Quality, personal commun., February, 2005).

A review of ADEQ's leaking underground storage tank (LUST) database (Arizona Department of Environmental Quality, 2003c) indicates that 278 incidents have occurred within the basin since 1985, of which 34 sites are currently under investigation. While these LUST sites pose a potential localized threat to groundwater, the threat is not regional in nature.

In summary, while a number of localized water quality problems exist in the Sierra Vista sub-basin, the use of groundwater is not resulting in actual or threatened water quality degradation in the sub-basin. Local water quality problems are being addressed through local, state and federal efforts.

Allen Flat Sub-Basin

Groundwater quality of the Allen Flat sub-basin was investigated by Burtell (1989). In that study, samples from 34 wells and springs were examined for major ion and silica concentrations. The results indicated that the dominant water type was calcium-bicarbonate (Ca-HCO_3) however, sodium bicarbonate (Na-HCO_3) waters were detected in eleven samples. In general, Burtell (1989) identified the groundwater of Allen Flat as good quality water.

In an effort to further characterize the groundwater quality, Burtell estimated the TDS by summing the concentrations of SiO_2 and major ions. Five of Burtell's samples were above 500 mg/l TDS. Four of these samples came from mountain-front wells where the dissolution of natural minerals is possibly contributing to the elevated TDS levels. The fifth however, came from a well located within 25 yards of a ranch house septic system. Three other wells are located within 75 yards of a septic system. All four of these wells produced samples with nitrate (NO_3^-) levels in excess of the representative background level of 10 mg/l; water from one well exceeded the drinking water standard of 45 mg/l (Burtell, 1989). Although not sampled in the study, there is also the possibility that other constituents (organic compounds, bacteria, and trace metals) may be leaching from septic systems in the area and potentially contaminating groundwater. Contamination from septic system leachate could become a more serious problem if the Allen Flat sub-basin is further developed and required setbacks of wells from septic tanks are not followed.

CHAPTER 3 - Impacts of Water Use on the Groundwater System

This Chapter discusses several recent studies of the basin, and the previous evaluation of the basin for AMA designation in 1988. These studies have attempted to forecast the impacts of various water use scenarios on the regional hydrologic system. This chapter includes the Department's findings based on recently measured data and analyses of recent studies in the basin.

Past Predictive Studies of the Basin

ADWR previously reviewed the basin for potential AMA designation in 1988 and found that conditions at that time did not exist for AMA designation. As part of that study, Putman and others (1988) used a USGS groundwater model (Freethey, 1982) to estimate the effect of groundwater pumping on groundwater depletions. The model covered a portion of the USP basin from the U.S.-Mexico border to Fairbank.

Putman and others (1988) made the following conclusions. Pumpage in the Sierra Vista sub-area had not affected that portion of the regional aquifer adjacent to the San Pedro River except near Hereford. This pumping was related to agricultural uses. Around the Sierra Vista area, groundwater modeling results indicated that continued groundwater pumpage between 1986 and the year 2000 would mine an additional 208,000 acre-feet of groundwater from the regional aquifer, resulting in a maximum groundwater decline of about 80 feet, at a maximum rate of about 6 feet per year. The updated model used to project water levels in the year 2000 showed that water levels in the regional aquifer several miles west of the San Pedro River would rise up to 20 feet at Hereford, would decline by about 10 feet west of Lewis Springs, and would decline by about 10 feet west of Charleston.

Additional findings by Putman and others (1988) stated that the artesian head present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River had decreased somewhat over time due to groundwater development in these areas. The extent of the decrease was difficult to quantify due to the lack of data. This conclusion was based on a comparison of descriptive reports on artesian conditions in very early hydrologic reports on the USP basin with later hydrologic reports on the area. The shallow floodplain aquifer, which underlies the San Pedro River, showed no long-term declines in water level. Putman and others (1988) predicted that the retirement of agricultural lands acquired by the U.S. Bureau of Land Management (BLM) in the San Pedro Riparian National Conservation Area (SPRNCA) would allow water levels in both the confined and unconfined regional aquifer to rise, enhancing groundwater discharge rates to the floodplain alluvium.

The 1988 report by Putman and others also concluded that no land subsidence had occurred in the USP basin (Strange, 1984) and that groundwater use was found not to be affecting water quality. There were no known regional water quality problems in the USP basin noted, although there were several local problems due to industrial and sewage treatment plant sources.

The next regional evaluation of the Sierra Vista sub-area was conducted by Vionnet and Maddock (1992), who developed a model of the basin that incorporated a refined modeling package to better simulate phreatophyte water use. This model was also based on Freethey (1982) and incorporated pumpage data from the Putman and others (1988) report. The evapotranspiration package used to model riparian water use had to be adjusted to a use rate of about half of the conceptual estimates. This is in line with more recent studies that indicate that the riparian community receives substantial supplies of water from rainfall events and bank storage after flood events and is not entirely dependent on a deep root system for water (Corell and others, 1996; Chehbouni and others, 2000; Snyder and Williams, 2000).

Eight years after the 1988 Putman and others report, the Department (Corell and others, 1996) developed a new groundwater model that covered most of the Sierra Vista sub-area. This model incorporated new information regarding conservation efforts by Fort Huachuca and Sierra Vista, as well as the retirement of agricultural lands due to the establishment of the SPRNCA by the BLM in 1988. The new model was used to project basin conditions between the years 1990 and 2030 (Corell, 1996).

Corell studied five alternative development scenarios at the request of the Upper San Pedro Technical Committee and the Cochise County Board of Supervisors (Corell, 1996). Scenarios were sketched out at the direction of the Technical Committee, which served as advisor to the Cochise County Board of Supervisors. These alternatives ranged from relatively low growth and low water use to relatively high growth and high water use. They also incorporated the retirement of agricultural lands south of Fairbank in several scenarios and the presence of recharge projects operated by Sierra Vista and Ft. Huachuca in others. Corell ran the future water use scenarios for the period 1990-2030. Full results are presented in Corell (1996).

The simulated groundwater-level changes shown in the results of the Department's 1996 model projections reflect an interplay between factors that increase or decrease water demand. Removing agricultural land from the southern part of the basin decreased groundwater withdrawals close to the San Pedro River, allowing groundwater levels to stabilize or rise. Construction of recharge projects by Sierra Vista and Fort Huachuca caused groundwater levels to rise near the projects and mitigated the cone of depression under Sierra Vista and Fort Huachuca. The recharge projects also caused groundwater levels between the project locations and the river to rise. These effects were offset by increasing demand from riparian growth within SPRNCA and from population growth in the model area. The rising groundwater levels simulated by some of the alternative scenarios were phenomena that lasted for several decades before declining due to increasing demand by municipalities, water companies, and rural residents.

The Commission for Environmental Cooperation (CEC) examined the USP basin in 1999 to determine strategies for preserving riparian habitat for migratory bird use. The CEC examined various tools available for hydrologic analysis and chose to use the Department's 1996 model of the Sierra Vista sub-area (Corell and others, 1996) to analyze several alternative water use scenarios. Their results were similar to Corell (1996). Many of the alternatives have institutional, legal, or economic constraints, but the range of solutions examined provides a good overview of alternative basin management strategies.

Goode and Maddock (2000) also estimated future water-use effects, using a groundwater model for the entire USP basin, including an area of land near Redington in the Lower San Pedro basin. Goode and Maddock developed a groundwater model that utilized earlier modeling studies by Putman and others (1988), Vionnet and Maddock (1992), and Jahnke (1994). They ran a number of development scenarios, ranging from relatively low groundwater use to relatively high use. Goode and Maddock used different methods of estimating mountain front recharge, phreatophyte use, and agricultural use than Corell and others (1996). The Goode and Maddock model also estimated agricultural acreage using a 1997 Landsat image. They estimated higher agricultural groundwater demands than did Corell (1996), even for the common area of both models. No ground-truthing was conducted for the Goode and Maddock model (Thomas Goode, personal commun. to Frank Putman, ADWR, February, 2003). The higher agricultural demand estimate resulted in simulation of greater groundwater level declines in their model projections. Goode and Maddock's agricultural groundwater demand was about 113,000m^3/d (about 33,400 acre-feet per year). Their model also simulated agricultural recharge of 30% of the groundwater demand, so their net agricultural groundwater use was about 23,400 acre-feet per year.

Goode and Maddock (2000) published estimated effects on the groundwater system in their report. Using a high water use scenario, the model showed drawdowns near Sierra Vista and Fort Huachuca of about 15 meters (49 feet) between 1997-2000 and 2020, and drawdowns of 5+ meters (16+ feet) near Benson. Using lower population growth and water use estimates resulted in groundwater level declines of about 5 meters (16 feet) near Sierra Vista during this same period, and groundwater level rises of about 3 meters (10 feet) near Benson.

ADWR Current Findings and Projections

ADWR's review of measured data and recent studies indicates that none of the predictive studies discussed above has precisely forecasted current hydrologic conditions in the USP basin. Groundwater modeling is an important tool that can help analyze many interpretive and predictive hydrologic studies. It is important to understand the limitations and possible sources of error however, since all models are based on a set of simplifying assumptions, which limit their use for certain problems. Discussed below are Department findings based on recently measured data and analyses of recent studies in the basin, as well as a comparison of the results of the predictive studies with current hydrologic conditions.

In the Sierra Vista area, the ADWR update of the USGS groundwater model (Putman and others, 1988) predicted a maximum decline of about 80 feet between 1986 and 2000, at a maximum rate of 6 feet per year. The actual maximum decline near Sierra Vista between 1990 and 2001 has been 15 feet, at an average of 1.4 feet per year, as shown in Figure 18 (Arizona Department of Water Resources, GWSI Data, 2002).

In the regional aquifer several miles west of the San Pedro River, the updated model (Putman and others, 1988) projected water levels in the year 2000 would rise up to 20 feet near Hereford, would decline by about 10 feet west of Lewis Springs, and would decline by about 10 feet west of Charleston. Actual measured changes in water levels between 1990 and 2001 have been on the order of –3 to +3 feet near Hereford, -3 to +4 feet west of Lewis Springs, and –4 to –6 feet west of Charleston as shown on Figure 18 (Arizona Department of Water Resources, GWSI Data, 2002).

Additional findings by Putman and others (1988) stated that the artesian head present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River had decreased somewhat over time due to groundwater development in these areas. In the Benson-Pomerene area, Barnes and Putman (2004) reported a modest water-level decline in the deeper (artesian) aquifer. Water-level changes in deep wells south of Pomerene ranged from a rise of 0.3 feet to a maximum decline of 19 feet, with most declines in the 4.0 to 9.0 foot range. In the St. David area, wells completed in the regional aquifer showed the least amount of change (Barnes and Putman, 2004). Hydrograph C on Figure 19 shows a gentle decline of the water level in the regional aquifer since 1990.

Putman and others (1988) stated that the shallow floodplain aquifer, which underlies the San Pedro River, showed no long-term declines in water level. The 1988 Putman and others report had predicted that the retirement of agricultural lands acquired by the U.S. Bureau of Land Management (BLM) in the SPRNCA would allow water levels in both the confined and unconfined regional aquifer to rise, particularly in the Hereford area, enhancing groundwater discharge rates to the floodplain alluvium. The Putman and others report (1988) also stated that the increase in flow may be offset if phreatophyte growth expanded into previously fallow land.

The shallow floodplain aquifer has shown variable changes of both rises and declines in water level from 1990 to 2001 (Barnes and Putman, 2004). This aquifer is recharged by the river and by groundwater discharge from the regional aquifer. Water levels in wells completed in the floodplain aquifer fluctuate seasonally in response to river flows, phreatophyte use, and pumpage. The recent drought conditions have reduced flow in the river, thus limiting recharge to the shallow floodplain aquifer and contributing to some observed declines (Barnes and Putman, 2004). North of Pomerene, water levels ranged from no change to a maximum rise of 11.1 feet, with an average rise of 4.7 feet. These measurements are mostly from shallow wells (Barnes and Putman, 2004). In the Benson-Pomerene area, water-level changes in the shallow aquifer ranged from a rise of 0.5 feet to a decline of 10.2 feet, with most declines in the 1.0 to 5.0 foot range. South of St. David, declines in the 1 foot per year range have been recorded in the shallow aquifer. The floodplain aquifer from the U.S.-Mexico border to State Route 90 has shown little change since 1990. The Palominas and Hereford area reflect water-level changes ranging from rises of 7.0 feet to declines of 4.9 feet, with most wells showing a change of plus or minus 3 feet

(Barnes and Putman, 2004). Hydrograph S of Figure 19 reflects the stable water-table conditions in the Palominas area. This hydrograph also shows that these water levels decline in dry seasons and dry years, but that they recover to their previous high levels following flood events of the San Pedro River.

Corell studied five alternative development scenarios for the period 1990-2030 that ranged from relatively low growth and low water use to relatively high growth and high water use (Corell, 1996). Corell's worst-case scenario of high growth, high evapotranspiration, and no recharge showed a 90 foot water-level decline in the Sierra Vista area by the year 2030. Other model assumptions for this scenario in 2030 included a population projection of 78,000, groundwater pumpage of 14,100 acre-feet per year, and riparian use of 10,000 acre-feet per year. In comparison, the Department's current projections for the year 2030 assume a higher population of 92,000, higher groundwater use of 22,600 acre-feet per year, more artificial recharge of 5,100 acre-feet per year (Table 3), and lower riparian use of 7,700 acre-feet per year (Table 5). From 1990-2001, the measured water-level decline rate in the Sierra Vista area was less than 1 foot per year. Department projections show a linear increase in both population and groundwater demand. Assuming a decline rate of 1 foot per year and all other conditions remaining constant, a water-level decline in the Sierra Vista area of about 40 feet would be expected for the period 1990-2030.

The Goode and Maddock study modeled the northern part of the sub-basin, but as discussed, agricultural use has actually reduced far below their assumptions. Goode and Maddock used a net agricultural groundwater demand of about 23,400 acre-feet in their model, which led to an overestimate of groundwater declines within the USP portion of their scenario. By way of contrast, ADWR's estimate of consumptive (net) agricultural groundwater use for 2002 is about 7,500 acre-feet for the USP basin. In their high water use scenario, Goode and Maddock eliminated agriculture within one mile of the San Pedro River. This run showed an estimated groundwater decline in the Benson area of up to 50 feet by 2020**.** The most recent water-level survey conducted by the Department showed that in the Benson-Pomerene area, wells completed in the shallow aquifer showed changes ranging from a rise of 0.5 feet to a decline of 10.2 feet between 1990 and 2001, with most declines in the 1.0 to 5.0 foot range. For the same period, water-level changes in deep wells in the Benson-Pomerene area ranged from a rise of 0.3 feet to a decline of 18.9 feet, with most declines in the 4.0 to 9.0 foot range (Barnes and Putman, 2004).

CHAPTER 4 - Hydrologic Summary and Recommendations

This chapter summarizes the hydrologic conditions in the USP basin and provides hydrologic recommendations. Continued groundwater withdrawals in excess of recharge will impact the groundwater resources of the basin. The magnitude and extent of these impacts depends on a number of factors including population growth, water demand rates, conservation efforts, effluent recharge, location of groundwater use, mountain front recharge and climate.

Summary

- The upper and lower alluvial aquifers contain an estimated 15.6 million acre-feet of groundwater. The Pantano (?) Formation contains between an estimated 3.8 million and 10.1 million acre-feet of water, and the floodplain aquifer contains an estimated 421,000 acre-feet of water. Thus, total groundwater storage in the Sierra Vista sub-basin is estimated to range between 20 million and 26 million acre-feet. These estimates are based on gravity studies by Gettings and Houser (2000) and Oppenheimer and Sumner (1980), on year 2001-2002 groundwater level data from the Department's GWSI database (Arizona Department of Water Resources, GWSI, 2002), and specific yield estimates are from Gettings and Houser (2000), Corell and others (1996), and from hydrologic literature. The annual change in groundwater storage for the USP basin is about -9,500 acre-feet per year (Table 5).

- Three deep alluvial troughs were identified in the Sierra Vista sub-basin by Gettings and Houser (2000), Halverson (1984), and Oppenheimer and Sumner(1980). Two of the structural troughs are located west of the San Pedro River and are north and south of Sierra Vista. A shallow area of hardrock trending east-west under Fort Huachuca, Sierra Vista, and Charleston separates two of the deep troughs to the north and south. The third trough is east of the San Pedro River and northwest of Tombstone.

- Between 1990 and 2001, the Sierra Vista cone of depression deepened slightly. The area within the cone of depression showed declines generally between 5 and 10 feet between 1990 and 2001 (see Figure 18), or between 0.5 to 1.0 foot per year (Barnes and Putman, 2004). An average groundwater decline rate of 1.4 feet per year was reported by Putman and others (1988) for this same area between about 1968 and 1986.

- In other areas of the USP basin, groundwater-level changes between 1990 and 2001 have ranged from a rise of 11 feet northwest of Pomerene to a decline of 32 feet west of Naco. Figure 18 shows water-level changes within specific areas of the basin for the 12-year period from 1990 through 2001.

- Cones of depression appear to be developing in an area west of Benson along Interstate 10 and southwest of Bisbee along Greenbush Draw. These cones are found close to well fields that supply municipalities. Planned development near Benson (Whetstone Ranch) will probably be served water by a wellfield near Benson, and a cone of depression southwest of Benson may develop as a result.

- The artesian heads present in some portions of the regional aquifer underlying the floodplain alluvium of the San Pedro River have decreased somewhat over time due to groundwater development in these areas. In the Benson-Pomerene area, Barnes and Putman (2004) reported a modest water-level decline in the deeper (artesian) aquifer. Artesian conditions continue to support modest groundwater discharges to wells in the Benson-Pomerene areas. Artesian conditions also exist in the Palominas-Hereford area but aquifer pressures were never sufficient for large-scale irrigation in this area (Bryan and others, 1934). Barnes and Putman (2004) report little change in water levels in wells in the Palominas-Hereford area.

- The shallow floodplain aquifer, which underlies the San Pedro River, has shown no long-term declines in water level. This aquifer is sustained by groundwater discharge from the basin-fill aquifer and recharge from flood events. The recent drought conditions have reduced flow in the river, thus limiting recharge to the shallow floodplain aquifer and contributing to some observed short-term declines (Barnes and Putman, 2004).

- No land subsidence has occurred in the USP basin to date (personal commun. with Ray Harris, Arizona Geological Survey, Tucson, AZ, and Don Pool, U.S. Geological Survey Hydrologic Investigations and Research Program, Tucson, AZ, 2002). Putman and others (1988) reported a similar finding of no land subsidence in the USP basin.

- There are no known regional water quality problems in the USP basin and no known water quality degradation has occurred from the use of groundwater. There are several local problems due to industrial, mining, municipal and military activities. Putman and others (1988) reported no known regional water quality problems in the basin, and similarly identified local water quality problems.

Recommendations

- ADWR should continue to measure groundwater levels in the basin. Groundwater measurement locations should recognize expected development patterns in the basin to the extent possible. Cooperation of local governments, water companies, and residents is vital in this respect.

- A cooperative water-level measurement program should be developed to cover the San Pedro drainage area between Cananea, Sonora and "The Narrows", north of Benson, Arizona. Annual groundwater withdrawal data and information about groundwater use in the Mexican portion of the basin would be useful in understanding the entire San Pedro basin.

- Riparian use and mountain front recharge in the USP basin are among the largest and least certain components of the water budget, particularly for the Benson sub-area. Research to determine the water needs of the riparian community should be continued. Research should also include groundwater level monitoring in the floodplain aquifer and the underlying regional aquifer, as well as studies to quantify mountain front recharge.

- Water conservation efforts and implementation of recharge projects have positive benefits in reducing groundwater overdraft as indicated by modeling studies and by recent data collected by the Department. Such local efforts should be continued throughout the basin.

- The Benson sub-area has received less scientific attention than the Sierra Vista sub-area. More research focusing on hydrologic processes in this part of the USP basin is encouraged.

- The USGS streamflow gaging stations within the USP basin should be continued. The feasibility of re-installing a gaging station at “The Narrows” should be investigated to provide a measure of basin outflows and to permit construction of a more accurate water budget.

- Groundwater models, together with updated water demand and supply information, may be used to guide basin-wide water management decisions. Assumptions regarding water demands and recharge should continue to receive rigorous scrutiny when evaluating model results.

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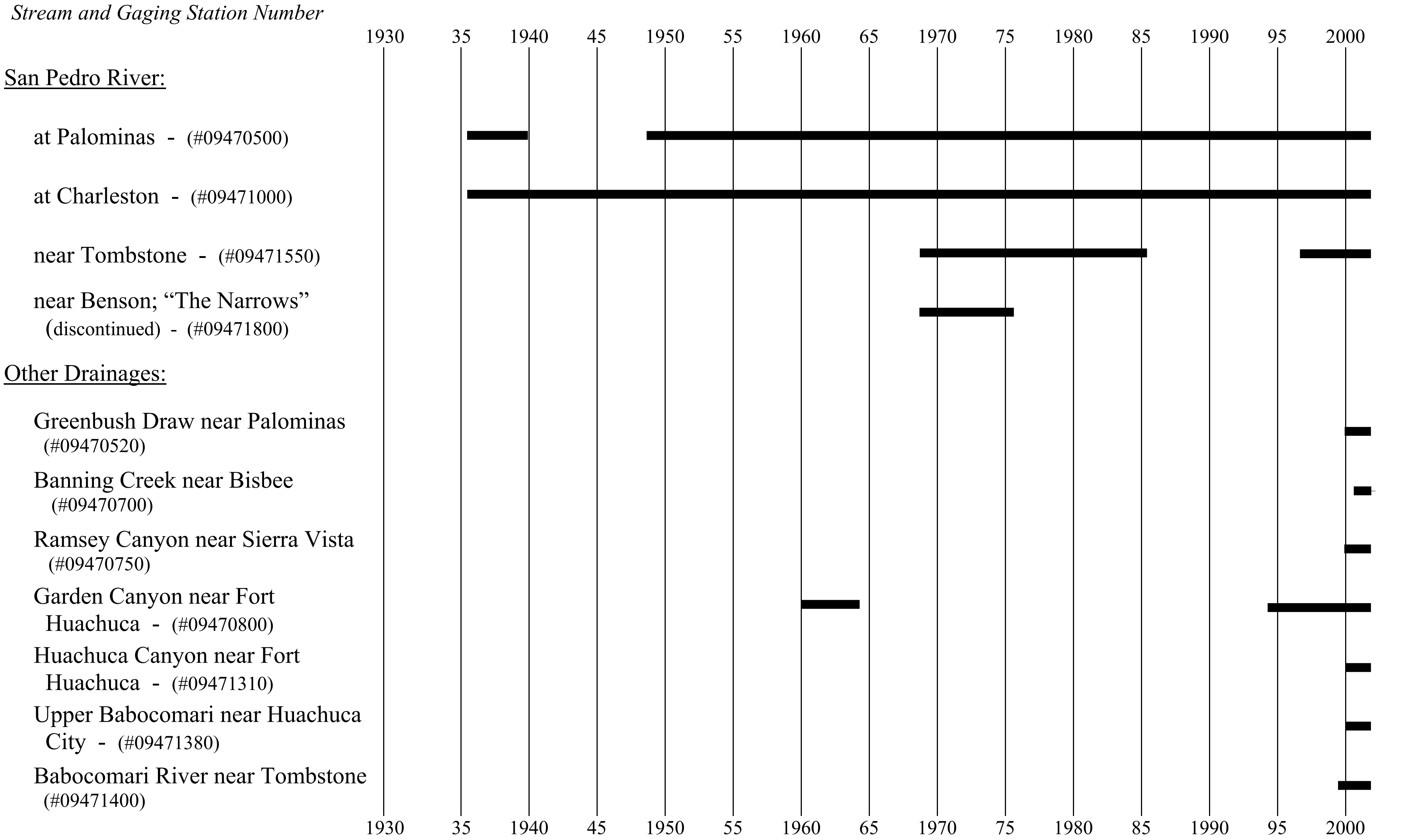
Appendix A

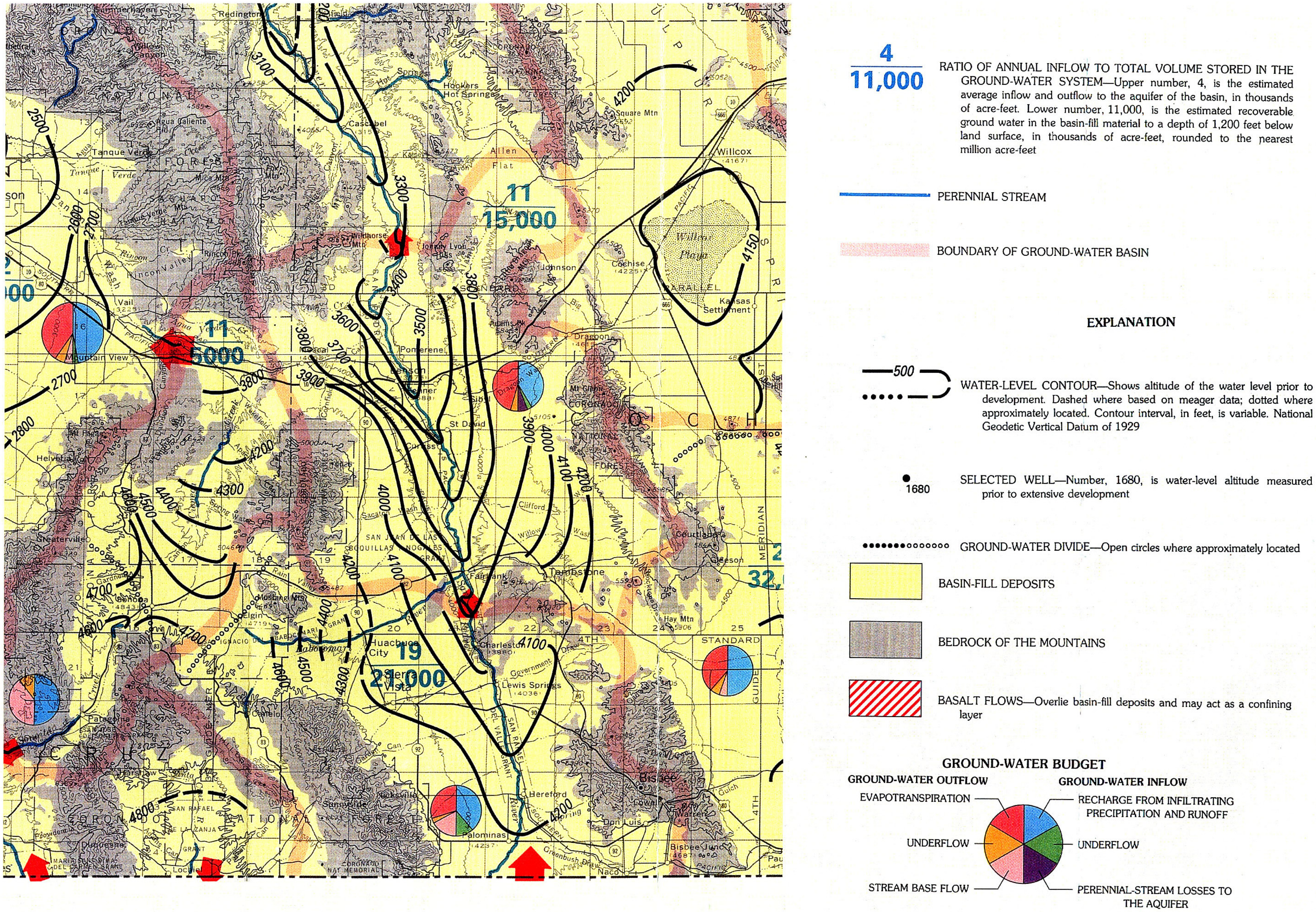
Period of Record for USGS Stream Gaging Stations in the Upper San Pedro Basin.



Source: U.S. Geological Survey, Water Resources Data, Arizona, Water Year 2001

Appendix B

Predevelopment Hydrologic Conditions in the Upper San Pedro Basin and Adjacent Basins



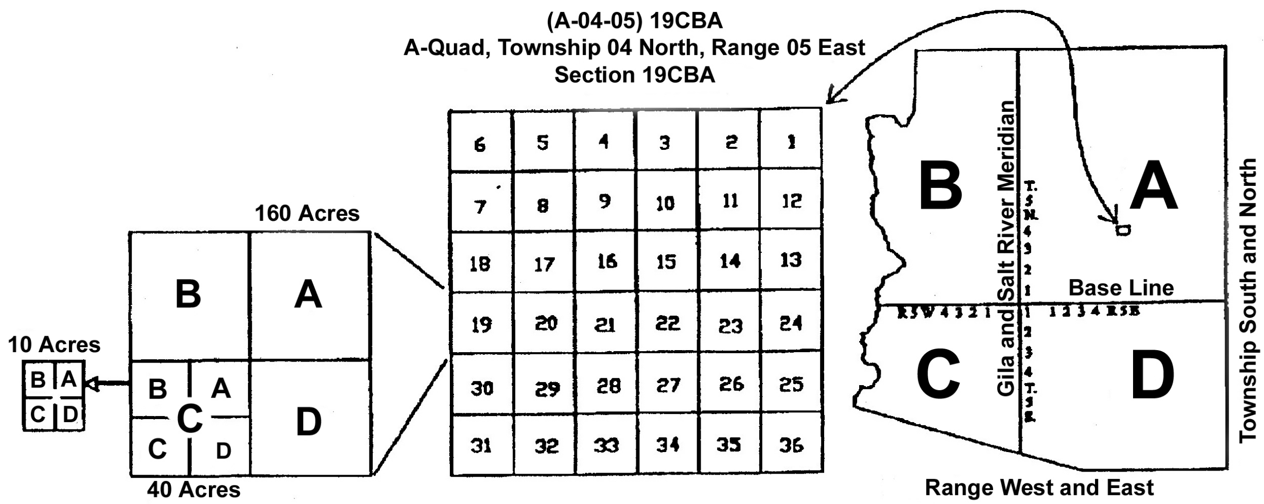
Source: Modified from Freethey and Anderson, 1986, Sheet 3.

Appendix C

Well Numbering System

The well numbering system in Arizona is based on the Gila and Salt River baseline and meridian (GSRB&M) which divide the state into four quadrants (Figure 8). These quadrants are designated counter clockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west is in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters are also assigned in a counter clockwise direction, beginning in the north east quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown in Figure 8, well number (A-4-5) 19cba designates the well as being in the SW¼ NW¼ NE¼ Sec.19, T. 4 N., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Well Numbering System in Arizona.



Appendix D

ADWR Crop Survey of the Benson Sub-area, May 1 – 3, 2002

ADWR staff conducted a crop survey of the Benson sub-area from May 1st to May 3rd, 2002. The survey area extends from the St. David Irrigation District diversion north to the "Narrows" about 10 miles north of Benson. The survey area includes two surface water irrigation providers, St. David Irrigation District, Pomerene Water Users Association that divert water from the San Pedro River and non-district irrigation users in Benson and between Pomerene and the "Narrows."

The St. David Irrigation District (SDID) is located in and around the community of St. David. The SDID diversion is an earthen dam, which diverts the San Pedro River to acreage located on the east side of the San Pedro River. The district diverts water whenever flows in the river are sufficient for irrigation. The SDID operates two wells located about 1.5 miles north of the diversion. The wells provide supplemental water and they are used during periods when surface water is insufficient or unavailable to meet the District's needs. In addition, private wells are used to irrigate when surface water supplies are low. On May 1st, 2002 ADWR visited the SDID diversion and noted some water impounded by the dam. However, there was not enough water to be conveyed to the first field about 1.5 miles north. ADWR investigators observed an SDID well discharging water into the District's ditch and conveying water north towards St. David. The investigators also observed irrigators pumping from their private wells for irrigation on their properties.

The Pomerene Water Users Association (PWUA) service area includes the acreage east of the San Pedro River from the diversion and north several miles to Pomerene. The Association does not supplement surface water with well water because it does not own irrigation wells. Many individuals irrigate from their wells on their property, and a private well pumps into the PWUA canal to convey water to a portion of the system when surface water is unavailable. On May 2nd, ADWR visited the PWUA diversion and there was not enough water in the canal to reach the service area. Flowing water was observed in the canal near Pomerene but the source was not observed. Many individual irrigators were pumping from their wells to irrigate their fields.

Non-district irrigators in the Benson sub-area are located outside of the SDID and PWUA service areas. There are no surface water diversions by these irrigators and irrigation is supplied by well water.

ADWR staff identified and mapped survey area irrigation on the 1992 USGS Benson photo-quad, 1:10,560 scale and the 1996 USGS Galleta Flat East, Land and St. David photo-quads, 1:14,080 scale. The crop survey started at the first field along the SDID ditch approximately ½ mile north of the diversion and it was conducted systematically through St. David, Benson, Pomerene and up the San Pedro River to the "Narrows." Observations were recorded, mapped and some photographs and GPS locations were recorded in certain locations.

ADWR investigators examined agricultural and non-agricultural acreages supplied by surface water and wells in the Benson sub-area. Agricultural irrigation supplies water to farm crops in fields and there is non-agricultural irrigation of golf course and school yard turf, and landscapes associated with domestic use. Crops were identified, field conditions and irrigation delivery systems were observed, and the irrigation status was determined from on-site observations. Generally most property was accessible and observations were made as near the fields as possible. Some properties were posted "no trespassing" or gates were locked which limited access to fields. Also, some fields were surrounded by vegetation or were located far from entrance gates. Consequently some fields were observed from a distance but at the best possible vantage point. Lands that were not observed were not mapped.

ADWR determined that 5,707 acres can be irrigated with well water throughout the Benson sub-area and 2,407 of those acres can be irrigated with surface water from the San Pedro River in the SDID and PWUA service areas. Outside of the irrigation district service areas well water is used exclusively to potentially irrigate about 3,300 acres. Table D-1 shows the acreage of agricultural and non-agricultural irrigation and the water sources in the Benson sub-area.

Table D-1. Agricultural and Non-Agricultural Potential Irrigation.
(All acres were not irrigated in May, 2002)

	BENSON SUB-AREA Surface and Well Water (acres)	ST. DAVID IRRIGATION DISTRICT Surface and Well Water (acres)	POMERENE WATER USERS ASSOCIATION Surface and Well Water (acres)	NON – DISTRICT Well Water (acres)
Agriculture	5,675	1,119	1,285	3,271
Non-Agriculture	32	3	0	29
TOTAL	5,707	1,122	1,285	3,300

ADWR observed and recorded the crop type, irrigation system type, field conditions and determined the irrigated acres. The crop survey allowed ADWR to classify irrigated acreages as "active irrigation" and "not actively irrigated." Irrigation use was determined by the presence or absence of a crop and conveyance system, and by the apparent condition of the crop, conveyance system and field. An irrigated field was identified as acreage that had an actively irrigated crop and the conveyance system and field appeared to be maintained for continued irrigation use. Fallow fields were identified as acreage that did not have an actively irrigated crop, but the conveyance system and field appeared to be maintained for future irrigation use. Fields that were not irrigated were identified as acreage that did not have an actively irrigated crop, the conveyance system and field was not maintained or poorly maintained, and future use was uncertain. ADWR observed and mapped approximately 5,707 agricultural and non-agricultural acres and determined that 2,151 acres were irrigated, 420 acres were fallow, and 3,135 were not irrigated.

Table D-2 shows the agricultural and non-agricultural irrigation classifications and water sources in the Benson sub-area.

Table D-2. Agricultural and Non-Agricultural Irrigation Classifications.

	BENSON SUB-AREA *Surface and Well Water* (acres)	ST. DAVID IRRIGATION DISTRICT Surface and Well Water (acres)	POMERENE WATER USERS ASSOCIATION Surface and Well Water (acres)	NON – DISTRICT Well Water (acres)
AGRICULTURAL IRRIGATION				
Irrigation	2,120 (37%)	417	427	1,277
No Irrigation	3,135 (55%)	640	673	1,822
Fallow	420 (7%)	62	186	172
TOTAL	5,675 (100%)	1,119	1,286	3,271
NON-AGRICULTURAL IRRIGATION				
Irrigation	31	3		29
No Irrigation				
Fallow				
TOTAL	31	3		29

Table D-2 shows that ADWR observed about 2,120 acres of agricultural irrigation and only 31 acres of non-agricultural irrigation. Since the non-agricultural portion is relatively small, this report hereon will combine agricultural and non-agricultural irrigation acreage and describe and summarize it simply as irrigation acreage.

ADWR identified the non-deficit and deficit irrigation practices on actively irrigated acreage. Investigators observed and compared similar fields with the same crop type. A sufficiently irrigated crop generally exhibited healthy dense growth, green vegetation, uniform and even cover. A deficit-irrigated crop generally appeared stressed and sparse, short or stunted, thin, pale or brown, non-uniform or uneven throughout the field. Table D-3 lists the plant and soil characteristics that were observed to determine normal and deficit irrigation.

Table D-3. Plant and Soil Characteristics of Normal and Deficit Irrigation Practices.

CHARACTERISTICS	NORMAL IRRIGATION	DEFICIT IRRIGATION
APPEARANCE	Healthy, turgid, erect, green to pale green	Stressed, wilted, limp, pale green to brown
GROWTH	Dense, uniform height and thickness	Thin, stunted, non-uniform height and thickness
COVER	Uniform density, evenly distributed, few bare spots	Non-uniform density, sparse, patchy or uneven, many bare spots.
SOIL	Irrigated, wet or moist	Not irrigated, dry, cracked, dusty

The irrigation status, described in terms of normal and deficit irrigation, is shown in Table D-4. These terms correspond to a level of irrigation and the associated crop and soil characteristics described in Table D-3. ADWR determined there were approximately 1,689 non-deficit irrigation acres and 462 deficit irrigation acres in the Benson sub-area. Table D-4 describes the irrigation status and acreage of all areas in the sub-area.

Table D-4. Irrigation Status.

STATUS	BENSON SUB-AREA	ST. DAVID IRRIGATION DISTRICT (acres)	POMERENE WATER USERS ASSOCIATION (acres)	NON – DISTRICT (acres)
Non-deficit irrigation	1,689 (79%)	210	395	1,085
Deficit Irrigation	461 (21%)	210	32	221
TOTAL	2,150 (100%)	420	427	1,306

The main types of irrigation observed in the Benson sub-area were flood (without tailwater pumpback systems) and sprinkler systems. A drip system was used in one location. Flood irrigation methods included basin, border, furrow and wildflood methods. Sprinkler systems included side-roll, center pivot and solid set. Table D-5 describes the irrigation systems and associated acreage in the Benson sub-area.

Table D-5. Irrigation Systems.

SYSTEMS	BENSON SUB-AREA (acres)	ST. DAVID IRRIGATION DISTRICT (acres)	POMERENE WATER USERS ASSOCIATION (acres)	NON – DISTRICT (acres)
Drip	4	4	0.0	0.0
Flood (w/o pumpback)	997	388	330	281
Sprinkler	1149	28	97	1024
TOTAL	2150	420	427	1305

ADWR observed about 997 acres that were flood irrigated, 1,149 acres irrigated by sprinklers, and just 4 acres irrigated by a drip system for a total of approximately 2,151 acres of active irrigation. The dominant crop was pasture with about 1, 993 irrigated acres. The remaining acreage included approximately 127 acres of grass, fruit trees, pasture and pecans, pine trees and vegetables, and 31 acres of non-agricultural crops including turf, landscape and fruit trees associated with domestic use. Table D-6 is a summary of the irrigated crops and acreage in the Benson sub-area.

Table D-6. Irrigated Crops.

CROPS	BENSON SUB-AREA (acres)	ST. DAVID IRRIGATION DISTRICT (acres)	POMERENE WATER USERS ASSOCIATION (acres)	NON – DISTRICT (acres)
Fruit Trees	8			8
Grass	7	7	0	0
Landscape	6	0	0	6
Pasture	1,993	334	427	1,233
Pasture & Pecans	48	48	0	0
Pecan Trees	36	27	0	10
Pine Trees	28	0	0	28
Turf	24	3	0	21
Vegetables	2	2	0	0
TOTAL	2,152	421	427	1,306

Appendix E

Groundwater Use Estimates for Riparian Inventory of the Benson Sub-area

(Includes the area north of SPRNCA, inside the Roeske and Werrell (1973) Qal, and excludes irrigated areas from ADWR HSR)

Estimates of riparian groundwater use were derived from combining aerial photo analysis (Arizona Regional Image Archive (ARIA), 2004; U.S. Fish and Wildlife Service, 2002) with data from recently completed studies (Scott and others, 2004, in preparation; Dahm and others, 2002).

Riparian classifications and delineations were obtained from the National Wetlands Inventory, San Pedro River Wetland/Riparian Project, with digital orthophoto quadrangles dated December, 2001 (U.S. Fish and Wildlife Service, 2002). The class is defined by the tallest vegetation, making up at least 30% cover (U.S. Fish and Wildlife Service, 2002). No more than two dominance types are included in mixed classes, each with at least 30% cover (U.S. Fish and Wildlife Service, 2002). Flights to obtain aerial photography originally scheduled for early Fall, 2001 were delayed until December, 2001 due to weather. Some ground-truthing was conducted with good comparison to photointerpretation (David Dall, Regional Wetlands Coordinator, USFWS, personal commun., May, 2004).

Riparian community types and acreage estimates delineated initially by the National Wetlands Inventory were compared with May, 1996 imagery obtained from ARIA (2004) to obtain average densities of percent canopy cover. These data were then combined with community type use rates adapted from Scott and others (2004, in preparation) and Dahm and others (2002) to estimate riparian groundwater use (Table E-1).

The two mesquite vegetative categories (forested and scrub/shrub mesquite) comprising the majority of the riparian acreage in the Benson sub-area were assessed in greater detail for the St. David, Benson, and Galleta Fat East quadrangles. The other two quads, Land and Wildhorse Mountain (at far south and north end, respectively), contained minimal acreage which could be assessed readily. These two mesquite classifications identified by the National Wetlands Inventory were compared with the ARIA imagery to obtain an estimate of canopy cover density for each polygon delineated. Following the tabulation of acreages and corresponding canopy cover ranging in density from 30 – 90 percent, consumptive use estimates were totaled for each mesquite vegetative class (Table E-2).

The following summarizes the methodology used and assumptions made in estimating riparian groundwater use.

1. Consumptive use estimates for salt cedar were adapted from Dahm and others (2002). Consumptive use estimates for all other vegetative classes were adapted from Scott and others (2004, in preparation).

2. Dahm and others (2002) measured an average growing season evapotranspiration (ET) of a moderately-dense stand of salt cedar at 750 mm/yr. This non-flooding Sevilleta site along the Rio Grande is a few hundred meters away from the river with a depth to water of 2 m. Salt cedar is able to survive in water poor conditions; but are stressed when depth to water exceeds 4 m below land surface. For a moderately dense, monotypic stand where depth to water was greater than 4 m, ET was greatly reduced to half the transpiration rate found in a similar stand where depth to water was 2-3 m below land surface (Cliff Dahm, personal commun., May, 2004).

Salt cedar consumptive use along the intermittent reach of the San Pedro River where depth to water is greater than 13 ft (4 m) is estimated at 375 mm/yr. In the younger alluvium adjacent to the San Pedro River in the Benson sub-area, the depth to water ranges from 10-50 feet below land surface (Arizona Department of Water Resources, 2002, Groundwater Site Inventory). Most of the vegetation delineated as salt cedar is in an area where depth to water exceeds 13 ft (4 m); therefore, the consumptive use at the Sevilleta site (Dahm and others, 2002) was halved to account for the greater depth to water along the intermittent reach of the San Pedro River.

3. Consumptive use estimates for cottonwood and mesquite along the San Pedro River in the Benson sub-area are from estimates reported by Scott and others (2004, in preparation) from their work conducted in the SPRNCA. The estimated total groundwater use for cottonwood/willow along an intermittent reach was 410 mm and along a perennial reach was 970 mm in 2003 (Scott and others, 2004, in preparation, Table 4-1). The estimated total groundwater use for mesquite (average of measurements from 2001, 2002, and 2003) was 464 mm at 74% aerial coverage (Scott and others, 2004, in preparation; Table 3-1).

4. The "mixed deciduous/evergreen" classification was assumed to be similar to mixed deciduous, since the evergreen species listed on the U.S. Fish and Wildlife Service National Wetlands Inventory classification system (juniper, white spruce, emory oak, and blue spruce) are not likely to occur at the riverbed elevation of the San Pedro River.

5. The "forested mixed deciduous" classification was assumed to have an average canopy cover of 80% density (ARIA, 2004). This classification was assigned a vegetative mix of 30% mesquite, 30% salt cedar, and 20% cottonwood/willow with a total groundwater use of 446 mm/yr.

6. The "scrub/shrub mixed deciduous" classification was assumed to have an average canopy cover of 60% density (ARIA, 2004). This classification was assigned a vegetative mix of 25% mesquite, 25% salt cedar, and 10% cottonwood/willow with a total groundwater use of 335 mm/yr.

7. The "mesquite/salt cedar" classification was assumed to have an average canopy cover of 70% density (ARIA, 2004). This classification was assigned a mix of 50% mesquite and 20% salt cedar with a total groundwater use of 410 mm/yr.

8. The "salt cedar/mesquite" classification was assigned a mix of 50% salt cedar and 20% mesquite with a total groundwater use of 374 mm/yr.

9. The "forested broad-leaf" classification was given the same consumptive use rate as cottonwood with a total groundwater use of 410 mm/yr.

10. The "needle-leafed deciduous" classification was given the same consumptive use rate as salt cedar with a total groundwater use of 375 mm/yr.

Table E-1. Groundwater Use Estimates for Riparian Inventory of the Benson Sub-area.

(Includes the area north of SPRNCA, inside the Roeske and Werrell (1973) Qal, and excludes irrigated areas from ADWR HSR)

Land Quadrangle

Attributes	Description	Acres	Consumptive Use Rate (mm/yr)	Consumptive Use Rate (in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1FO6CW	Forested Cottonwood	10.20	410	16.14	164.63	13.72
RP1FO8MD	Forest Mixed Decid/Evergr	8.42	446	17.56	147.86	12.32
RP1SS6MQ	Scrub/Shrub Mesquite	86.00	310	12.21	1,050.06	87.51
RP1226SC	Scrub/Shrub Salt Cedar	17.27	375	14.76	254.91	21.24
					Quad Total CU (ac-ft/yr)	134.79

St. David Quadrangle

Attributes	Description	Acres	Consumptive Use Rate (mm/yr)	Consumptive Use Rate (in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1FO6CW	Forested Cottonwood	38.39	410	16.14	619.61	51.63
RP1FO6MD	Forested Mixed Decid	55.74	446	17.56	978.79	81.57
RP1FO6MQ	Forested Mesquite	94.48	464	18.27	1,726.15	143.85
RP1SS6MD	Scrub/Shrub Mixed Decid	66.83	335	13.19	881.49	73.46
RP1SS6MQ	Scrub/Shrub Mesquite	388.00	*	*	*	453.41
RP1SS6MQ/SC	Scr/Shr Mesq/Salt Cedar	12.17	410	16.14	196.42	16.37
RP1SS6SC	Scrub/Shrub Salt Cedar	65.60	375	14.76	968.26	80.69
RP1SS6SC/MQ	Scr/Shr Salt Cedar/Mesq	98.78	374	14.72	1,454.04	121.17
					Quad Total CU (ac-ft/yr)	1,022.14

Benson Quadrangle

Attributes	Description	Acres	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1FO6CW	Forested Cottonwood	3.30	410	16.14	53.26	4.44
RP1FO6MD	Forested Mixed Decid	374.79	446	17.56	6,581.31	548.44
RP1FO6MQ	Forested Mesquite	0.02	464	18.27	0.37	0.03
RP1SS6MD	Scrub/Shrub Mixed Decid	27.36	335	13.19	360.88	30.07
RP1SS6MQ	Scrub/Shrub Mesquite	1,088.30	*	*	*	1,347.46
RP1SS6MQ/SC	Scr/Shr Mesq/Salt Cedar	14.64	410	16.14	236.29	19.69
RP1SS6SC	Scrub/Shrub Salt Cedar	237.62	375	14.76	3,507.27	292.27
					Quad Total CU (ac-ft/yr)	2,242.41

Galleta Flat East Quadrangle

Attributes	Description	Acres	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
PF01Ch	Forested Broad-Leaf	13.17	410	16.14	212.56	17.71
RP1FO6CW	Forested Cottonwood	5.21	410	16.14	84.09	7.01
RP1FO6MQ	Forested Mesquite	622.90	*	*	*	961.13
RP1FO8MD	Forest Mixed Decid/Ever	5.00	446	17.56	87.80	7.32
RP1SS6CW	Scrub/Shrub Cottonwood	0.07	410	16.14	1.13	0.09
RP1SS6MQ	Scrub/Shrub Mesquite	996.50	*	*	*	1,204.95
RP1SS6SC	Scr/Shr Salt Cedar	273.62	375	14.76	4,038.63	336.55
RP1SS8MD	Sc/Sh Mixed Decid Evergr	161.51	335	13.19	2,130.32	177.53
					Quad Total CU (ac-ft/yr)	2,717.05

Wildhorse Mountain Quadrangle

Attributes	Description	Acres	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1FO6MQ	Forested Mesquite	23.77	464	18.27	434.28	36.19
RP1SS6MQ	Scrub/Shrub Mesquite	1.33	310	12.21	16.24	1.35
					Quad Total CU (ac-ft/yr)	37.54
					TOTAL	6,153.93

Notes:

*Refer to Table E-2 for consumptive use estimates of mesquite vegetative classifications from St. David, Benson and Galleta Flat East quadrangles.

Wetland/riparian classifications and delineations obtained from U.S. Fish & Wildlife Service, 2002, National Wetlands Inventory, San Pedro River Wetland/Riparian Project; photography - December, 2001; ADWR GIS map files \\adwrnetra\userlib\wrmrp\hydro\basins\uppersanpedro\projects\frankputman\spedrowetlandriprianinventory.

Two wetland emergent classifications totaling about 20 acres were not included in this analysis.

Depth to water in wells located in floodplain alluvium ranges from 10 - 50 feet below land surface; difference between water level elevation in wells and riverbed elevation ranges from 1 - 15 feet (Arizona Department of Water Resources, 2002, Groundwater Site Inventory).

Consumptive use estimates adapted from Cliff Dahm (Department of Biology, University of New Mexico, personal commun., May, 2004), Scott and others (2004, in preparation), and Dahm and others (2002).

Table E-2. Groundwater Use Estimates for Mesquite Vegetative Classifications of the Benson Sub-area.

(Includes the area north of SPRNCA, inside the Roeske and Werrell (1973) Qal, and excludes irrigated areas from ADWR HSR)

St. David Quadrangle

Attributes	Acres	% Canopy Cover	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1SS6MQ	194	50	310	12.20	2,367.72	197.31
Scrub/Shrub	99	60	372	14.65	1,449.92	120.83
Mesquite	95	70	434	17.09	1,623.23	135.27
	388				Total CU (ac-ft/yr)	453.41

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Benson Quadrangle

Attributes	Acres	% Canopy Cover	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1SS6MQ	23.3	70	434	17.09	398.12	33.18
Scrub/Shrub	15.8	50	310	12.20	192.83	16.07
Mesquite	44.2	40	248	9.76	431.56	35.96
	152.8	50	310	12.20	1,864.88	155.41
	60.7	70	434	17.09	1,037.16	86.43
	37.7	30	186	7.32	276.07	23.01
	181	80	496	19.53	3,534.49	294.54
	8.1	70	434	17.09	138.40	11.53
	3.7	60	372	14.65	54.19	4.52
	2.7	60	372	14.65	39.54	3.30
	13.9	70	434	17.09	237.50	19.79
	62.4	40	248	9.76	609.26	50.77
	181	80	496	19.53	3,534.49	294.54
	8.1	70	434	17.09	138.40	11.53
	3.7	60	372	14.65	54.19	4.52
	2.7	60	372	14.65	39.54	3.30
	13.9	70	434	17.09	237.50	19.79
	62.4	40	248	9.76	609.26	50.77
	181	80	496	19.53	3,534.49	294.54
	8.1	70	434	17.09	138.40	11.53
	3.7	60	372	14.65	54.19	4.52
	2.7	60	372	14.65	39.54	3.30
	13.9	70	434	17.09	237.50	19.79
	62.4	40	248	9.76	609.26	50.77
	44.4	70	434	17.09	758.65	63.22
	198.9	60	372	14.65	2,913.02	242.75
	49.1	70	434	17.09	838.95	69.91
	16.4	70	434	17.09	280.22	23.35
	11.5	70	434	17.09	196.50	16.37
	161.7	60	372	14.65	2,368.20	197.35
	2.7	60	372	14.65	39.54	3.30
	13.9	70	434	17.09	237.50	19.79
	62.4	40	248	9.76	609.26	50.77
	44.4	70	434	17.09	758.65	63.22
	198.9	60	372	14.65	2,913.02	242.75
	49.1	70	434	17.09	838.95	69.91
	16.4	70	434	17.09	280.22	23.35
	11.5	70	434	17.09	196.50	16.37
	161.7	60	372	14.65	2,368.20	197.35
	1088.3				Total CU (ac-ft/yr)	1,347.46

Galleta Flat East Quadrangle

Attributes	Acres	% Canopy Cover	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1F06MQ	135.6	80	496	19.53	2,647.94	220.66
Forested	271.3	80	496	19.53	5,297.83	441.49
Mesquite	107.9	75	465	18.31	1,975.33	164.61
	102.1	60	372	14.65	1,495.32	124.61
	6	80	496	19.53	117.17	9.76
	622.9				Total CU (ac-ft/yr)	961.13

	Acres	% Canopy Cover	Consumptive Use Rate (mm/yr)	(in/yr)	Total Consumptive Use (in/yr)	Total Consumptive Use (ac-ft/yr)
RP1SS6MQ	28.3	80	496	19.53	552.63	46.05
Scrub/Shrub	9	80	496	19.53	175.75	14.65
Mesquite	70.6	80	496	19.53	1,378.65	114.89
	11.4	80	496	19.53	222.61	18.55
	9.6	90	558	21.97	210.90	17.57
	41.9	70	434	17.09	715.93	59.66
	9.6	40	248	9.76	93.73	7.81
	9.5	40	248	9.76	92.76	7.73
	15.2	40	248	9.76	148.41	12.37
	6	70	434	17.09	102.52	8.54
	60.3	60	372	14.65	883.13	73.59
	57.9	70	434	17.09	989.31	82.44
	105.6	50	310	12.20	1,288.82	107.40
	94.4	40	248	9.76	921.70	76.81
	66.6	60	372	14.65	975.40	81.28
	270.4	60	372	14.65	3,960.19	330.02
	23.4	50	310	12.20	285.59	23.80
	11.2	30	186	7.32	82.02	6.83
	11.4	40	248	9.76	111.31	9.28
	33.5	70	434	17.09	572.40	47.70
	36.1	50	310	12.20	440.59	36.72
	4.1	50	310	12.20	50.04	4.17
	10.5	80	496	19.53	205.04	17.09
	996.5				Total CU (ac-ft/yr)	1,204.95

Notes:

Percent canopy cover estimated from May 1996 imagery obtained from Arizona Regional Image Archive (2004).

Digital orthophoto quarter quads (DOQQ) utilized included St. David SW; Benson NE, SE; Galleta Flat East - NE, NW, SE (Arizona Regional Image Archive, 2004).